GEOTECHNICAL PROPERTIES OF LIGHTLY CEMENTED FLY ASH

A Thesis submitted in partial fulfillment of the requirements for the award of the Degree of

Master of Technology
in
Geotechnical Engineering
By

MAMATA MOHANTY

DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008,
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Under the guidance of

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CERTIFICATE

This is to certify that the project entitled ***Geotechnical properties of lightly cemented Fly ash*** submitted by **Mamata Mohanty** (Roll No. 210CE1019) in partial fulfillment of the requirements for the award of Master of Technology Degree in Civil Engineering at NIT Rourkela is an authentic work carried out by him under my supervision and guidance.

Date:

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ACKNOWLEDGEMENT

First of all I would like to express my heartfelt gratitude to Prof. Suresh Prasad Singh for his able guidance, support and suggestions throughout the project. I thank NIT Rourkela for giving me the opportunity to utilize the available resources. I would like to extend my gratefulness to Prof. N. Roy, Head, and Department of Civil Engineering. I wish to thank Meena Murmu, Research Scholar for his entire support throughout the project.

I am also thankful to all the staff members of Geotechnical Engineering laboratory for their assistance and co-operation during the course of experimentation.

I also thank all my batch mates who have directly or indirectly helped me in my project work and shared the moments of joy and sorrow throughout the period of project work.

Finally yet importantly, I would like to thank my parents and specially my sister who continuously motivated me.

Mamata Mohanty

Contents

SYNOPSIS

In India, about 76% of electrical energy is generated using coal as fuel in thermal power plants. Presently in India,170 millions of tones of fly is being produced by the of thermal power plants, out of which a vast majority is fly ash having low lime content. Fly ash is a solid waste generated by thermal power plants where coal is used as fuel. As the need of power is increasing with a very fast rate for development purpose, the production of fly ash is increasing rapidly while generating electrical energy by thermal power plant. Disposal of this enormous amount of fly ash faces problem of huge land requirement, transportation, and ash pond construction and maintenance, which can be reduced by utilizing fly ash as a construction material for civil engineering structures. For increasing the use of fly ash as a construction material, it is required to enhance some properties by stabilizing raw fly ash with suitable stabilizer like lime or cement. Fly ash becomes an attractive construction material because of its self hardening characteristics for which available free lime is responsible. The variation of its properties depends upon the nature of coal, fineness of pulverization, type of furness and firing temperature. Fly ash is of two types; Class C and Class F. Class C fly ash contains high calcium content which is highly reactivity with water even in absence of lime. Class F ash contains lower percentage of lime. The main work carried out is to investigate the suitability of class F fly ash, containing CaO as low as 1.4%, modified with added lime as a construction material in different civil engineering fields. Large scale utilization of Fly ash in geotechnical constructions will reduce the problems faced by the thermal power plants for its disposal mostly because of its property closely related with the natural earth material. So assessment of the behavior fly ash at different condition is required before its use as a construction material in Civil engineering structure. For judging the suitability of any material for different geotechnical engineering works its consistency properties, compaction properties, strength parameters and settlement properties are the most important parameters to be evaluated. In this work an attempt was made to evaluate the above said geo-engineering properties of fly ash collected from NSPCL-RSP captive plant along with the fly ash treated with different proportion of lime. The overall testing program is conducted in two phase. In first phase the physical and chemical characteristics of the fly ash samples were studied by conducting Hydrometer analysis, UCS test, Permeability test and CBR test. In second phase of the test programme fly ash mixed with 1%, 2%,5% and 10% of lime. Lime added in percentage

of dry weight of Fly ash. The geotechnical property of this lime stabilized fly ash sample were evaluated and compared with that of Fly ash. Based on the experimental findings the following conclusions are drawn:

- The fly ash consists of grains mostly of fine sand to silt size with uniform gradation of particles. The percentage of Fly ash passing through 75μ sieve was found to be 86.62%. Coefficient of uniformity (Cu) and coefficient of curvature (Cc) for Fly ash was found to be 5.88 & 1.55 respectively, indicating uniform gradation of samples. The specific gravity of particles is lower than that of the conventional earth materials.
- An increase in compaction energy results in closer packing of particles resulting in an increase in dry density where as the optimum moisture content decreases.
- Dry unit weight of compacted specimens is found to change from 1.142 to 1.255 kJ/m^3 with change in compaction energy from 118.6kJ/m^3 to 2483 kJ/m3, whereas the OMC is found to decrease from 30.2 to 24.2 %. This shows that fly ash sample responds very poorly to the compaction energy. With addition of lime maximum dry density decreases and optimum moisture content increases. Addition of lime results in filling the voids of the compacted fly ash thus increases the density.
- The failure stresses as well as initial stiffness of samples, compacted with greater compaction energies, are higher than the samples compacted with lower compaction energy. However the failure strains are found to be lower for samples compacted with higher energies. The failure strains vary from a value of 0.75 to 1.75%, indicating brittle failures in the specimen.
- A linear relationship is found to exist between the compaction energy and unconfined compressive strength.
- The UCS value is found to change from 32.764 to 47.271 kPa with change in compaction energy from 118.6kJ/m^3 to 2483kJ/m^3 indicating that the gain in strength is not so remarkable. It revealed from the test results that a linear relationship exists between the initial tangent modulus with unconfined compressive strength and deformation modulus.
- Increase in curing period of lime treated fly ash specimen show improvement in the UCS value. However the gain in strength with curing period is more in initial days of curing which tends to decreases with increase in curing period.

- With increase in compaction energy followed by curing period shows a significant increase in strength due to closer packing of particles. Besides, when lime is small in quantity, that's about 1%, the strength improvement is practically negligible, even if cured for long. With increased lime content the pozzolanic reaction peaks up producing adequate amount of cementitious compounds leading to visible increase in strength. As the lime percentage increases this facilitates the pozzolanic reaction that form cementiceous gel that binds the particles. This process is catalyst by increase in curing period. Increased duration of curing, leading to prolonged pozzolanic reaction and result in increase in strength.
- The unit cohesion and the angle of internal friction vary from 10.7 to 13.4kPa and 24.84 to 27.34 degree with the change in compaction energy from 118.6 kJ/m^3 to 2483kJ/m^3. Low value of angle of internal friction is due to lack of proper interlocking among particles as the fly ash mostly contains spherical particles with uniform gradation. There is negligible increase in cohesion component with compaction energy.
- The highest unsoaked and soaked CBR value are found to be 25.39% and 1.546% at compaction energy of 2483 kJ/m3.This indicates that CBR value of compacted ash is very susceptible to degree of saturation.
- The unsoaked CBR value is more than soaked CBR value. Even after 28 days of curing of samples with lime content of 10% the soaked CBR value do not show significant improvement over unsoaked CBR. This indicates that, relatively large amount of the lime is needed to bind all the fly ash particles together, leading to visible increase in strength.
- Permeability decreases with increase in either compactive energy or lime content. Permeability is basically a function of grain size and compactive effort. With increase in lime content, pozzolanic reaction occurs which result in blocking of the flow paths thus reducing the value of coefficient of permeability of the lime treated fly ash specimens.

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NOTATION	DESCRIPTION
E	Compaction Energy, kJ/m3
OMC	Optimum Moisture Content, %
MDD	Maximum Dry Density, kN/m3
cu	Unit Cohesion, kN/m2
Φ	Angle of Internal Friction, degrees
UCS	Unconfined Compressive Strength, kN/m2
FS	Failure Strain, %
M.C	Moisture Content, %
CBR	California Bearing Ratio, %
Ei	Initial Tangent Modulus, kN/m2
Cu	Coefficient of uniformity
Cc	coefficient of curvature
G	Specific Gravity
NUCS	Normalized Unconfined compressive Strength

CHAPTER 1

INTRODUCTION

1.1. INTRODUCTION

The greatest challenge before the processing and manufacturing industries is the disposal of the residual waste products. Waste products that are generally toxic, ignitable, corrosive or reactive have detrimental environmental consequences. Thus disposal of industrial wastes is a major issue for the present generation. This major issue requires an effective, economic and environment friend method to tackle with the disposal of the residual industrial waste products. One of the common and feasible ways to utilize these waste products is to go for construction of roads, highways and embankments. If these materials can be suitably utilized in construction of roads, highways and embankments then the pollution problem caused by the industrial wastes can be greatly reduced. But sufficient amount of soil of required quality is not available easily. So to meet the requirement of suitable amount of soil that to be used in the construction of roads and highways large amount of trees are being cut which cause deforestation, soil erosion and loss of fertile soil which also hampers in the agricultural productivity. Also, cost of extracting good quality of natural material is increasing. So effective uses of these industrial wastes which are used as a substitute for natural soil in the construction not only solve the problems of disposal and environmental pollution but also help to preserve the natural soil. This will provide a number of significant benefits to the constructing industry as well as to the country as a whole by conservation of natural resources, by reduction of volume of waste to landfills, by lowering the cost of construction materials, and by lowering waste disposal costs. One of the industrial wastes used as a construction material is the fly ash. In many countries, coal is the primary fuel in thermal power stations and other industries. The fine residue from the burnt coal is carried in the flue gas, separated by electrostatic precipitators, and collected in a field of hoppers. This residue called fly ash is considered to be an industrial waste. The fly ash is disposed of either in the dry form or mixed with water and discharged as slurry into locations called ash ponds (wet method). The quantity of fly ash produced worldwide is huge and keeps increasing from year to year. Four countries, namely, China, India, Poland, and the United States, alone produce more than 270 million tons of fly ash every year. Less than half of this is used. The potential impacts on the environment suggest the need for proper disposal of fly ash and justify maximum utilization of fly ash when viable. For increasing use of fly ash as a construction material, it is required to enhance some properties by stabilizing raw fly ash with suitable stabilizer like lime. The present project work aims at evaluating the effectiveness of lime in stabilizing the waste products fly ash and its suitability to be used as a structural fills and embankment materials. Fly ash used in this project was collected from the thermal power plant of CPP- NSPCL, Rourkela Steel Plant.

1.2. Fly Ash: An Overview

Fly ash is a fine, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. When mixed with lime and water the fly ash forms a cementitious compound with properties very similar to that of Portland cement. Because of this similarity, fly ash can be used to replace a portion of cement in the concrete, providing some distinct quality advantages. The concrete is denser resulting in a tighter, smoother surface with less bleeding. Fly ash concrete offers a distinct architectural benefit with improved textural consistency and sharper detail. Fly Ash is also known as Coal ash, Pulverized Flue ash, and Pozzolona. Fly ash closely resembles volcanic ashes used in production of the earliest known hydraulic cements about 2,300 years ago. Those cements were made near the small Italian town of Pozzuoli - which later gave its name to the term "pozzolan". A pozzolan is a siliceous or siliceous/aluminous material that, when mixed with lime and water, forms ancementitious compound. Fly ash is the best known, and one of the most commonly used, pozzolans in the world. Instead of volcanoes, today's fly ash comes primarily from coal-fired electricity generating power plants. These power plants grind coal to powder fineness before it is burned. Fly ash - the mineral residue produced by burning coal - is captured from the power plant's exhaust gases and collected for use. Fly ash is a fine, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. The difference between fly ash and Portland cement becomes apparent under a microscope. Fly ash particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures. That capability is one of the properties making fly ash a desirable admixture for concrete.

1.3. Classification of Fly ash

As according to According to ASTM C 618-03(2003a) two major classes of fly ash are recognized. These two classes are related to the type of coal burned and are designated as Class F and Class C in most of the current literature.

Class F fly ash is normally produced by burning anthracite or bituminous coal while Class C fly ash is generally obtained by burning sub-bituminous or lignite coal. Presently, no appreciable amount of anthracite coal is used for power generation. Therefore, essentially all Class F fly ashes presently available are derived from bituminous coal. Class F fly ashes with calcium oxide (CaO) content less than 6%, designated as low calcium ashes, are not self hardening but generally exhibit pozzolanic properties. These ashes contain more than 2% unburned carbon determined by loss on ignition (LOI) test. Quartz, mullite and hematite are the major crystalline phases identified fly ashes, derived from bituminous coal. Essentially, all the fly ashes and, therefore, most research concerning use of fly ash in cement and concrete are dealt with Class F fly ashes. In the presence of water, the fly ash particles produced from a bituminous coal react with lime or calcium hydroxide to form cementing compounds similar to those generated on the hydration of Portland cement. Previous research findings and majority of current industry practices indicate that satisfactory and acceptable concrete can be produced with the Class F fly ash replacing 15 to 30% of cement by weight.

Use of Class F fly ash in general reduces water demand as well as heat of hydration. The concrete made with Class F fly ash also exhibits improved resistance to sulphate attack and chloride ion ingress.

Class C fly ashes, containing usually more than 15% CaO and also called high calcium ashes, became available for use in concrete industry only in the last 20 years in the 1970s. Class C fly ashes are not only pozzolanic in nature but are invariably self cementitious.

1.4. Lime: An Overview

Lime i.e. CaO or $Ca(OH)_2$, the burned byproduct of lime stone ($CaCO_3$), is one of the oldest developed construction materials. It has been used by man more than 2000 years ago. The Romans used soil-lime mixtures for construction of roads. However, its utility in the modern geotechnical engineering applications was limited until 1945, mostly due to lack of proper understanding of the subject. Today, lime stabilization of soils is being widely used in several constructions such as, highways, railways, airports, embankments, foundation base, slope protection, canal lining etc. This is primarily due to the overall economy, ease of construction, coupled with simplicity of this technology that provides an added attraction for the engineers. Several research works have been reported highlighting the beneficial effect of lime in improving the performance of soils.

Calcium oxide (CaO), commonly known as quicklime, is a widely used chemical compound. It is a white, caustic and alkaline crystalline solid at room temperature. As a commercial product, lime often also contains magnesium oxide, silicon oxide and smaller amounts of Aluminium oxide and Iron oxide. Lime is produced by calcinations of limestone in a lime kiln at temperatures above 1,000° C. Calcium carbonate ($CaCO_3$) is converted into calcium oxide (CaO) and carbon dioxide (CO2). Active calcium oxide is highly reactive. In finely ground burnt lime a high level (80-90%) of calcium oxide guarantees good stabilization reaction in the soil, favorable water reduction in the soil and a temperature increase upon slaking. Lime in the form of quicklime (calcium oxide–CaO), hydrated lime (calcium hydroxide –$Ca(OH)_2$), or lime slurry can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone – CaCO3) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. Hydrated lime reacts with clay Particles and permanently transforms them into a strong cementitious matrix. Most lime used for soil treatment is "high calcium" lime, which contains no more than 5 percent magnesium oxide or hydroxide. On some occasions, however, "dolomitic" lime is used. Dolomitic lime contains 35 to 46 percent magnesium oxide or hydroxide. Dolomitic lime can perform well in soil stabilization, although the magnesium fraction reacts more slowly than the calcium fraction. Sometimes the term "lime" is used to describe agricultural lime which is generally finely ground limestone, a useful soil amendment but not chemically active enough to lead to soil stabilization."Lime" is also sometimes used to describe byproducts of the lime manufacturing process (such as lime kiln dust), which, although they contain some reactive lime, generally have only a fraction of the oxide or hydroxide content of the manufactured product. In this manual, "lime" means quicklime, hydrated lime, or hydrated lime slurry.

The long-term performance of any construction project depends on the soundness of the underlying soils as unstable soils can create significant problems for pavements or structures. With proper design and construction techniques, lime treatment chemically transforms unstable soils into usable materials. Lime, either alone or in combination with other materials, can be used to treat a range of soil types. Mainly the degree of reactivity of lime with the soil and the ultimate strength of that stabilized layers will determine by the mineralogical properties of the soils. In general, fine-grained clay soils (with a minimum of 25 percent passing the #200 sieve (74mm) and a Plasticity Index greater than 10) are considered to be good soil for stabilization. Soils containing significant amounts of organic material (greater than about 1 percent) or sulfates (greater than 0.3 percent) may require additional lime and/or special construction procedures. Lime has a number of effects when added into soil which can be generally categorized as soil drying, soil modification, and soil stabilization.

a) Soil drying is a rapid decrease in soil moisture content due to the chemical reaction between water and quicklime and the addition of dry material into a moist soil.
b) Modification effects include: reduction in soil plasticity, increase in optimum moisture content, decrease in maximum dry density, improved compactibility, reduction of the soil capacity to swell and shrink, and improved strength and stability after compaction. These effects generally take place within a short time period after the lime is introduced – typically 1 to 48 hours – and are more pronounced in soils with sizable clay content, but may or may not be permanent.
c) Lime stabilization occurs in soils containing a suitable amount of clay and the propel mineralogy to produce long-term strength; and permanent reduction in shrinking, swelling and soil plasticity with adequate durability to resist the detrimental effects of cyclic freezing and thawing and prolonged soaking.

Lime stabilization occurs over a longer time period of “curing.” The effects of lime stabilization are typically measured after 28 days or longer, but can be accelerated by increasing the soil temperature during the curing period. A soil that is lime stabilized also experiences the effects of soil drying and modification. Stabilization occurs when the proper amount of lime is added to a reactive soil. Stabilization differs from modification in a way that a significant level of long-term strength gain is developed through a long-term pozzolanic reaction. This pozzolanic reaction is the formation of calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay mineral surface. This reaction can begin quickly and is responsible for some of the effects of modification. However, research has shown that the full term pozzolanic reaction can continue for a very long period of time - even many years - as long as enough lime is present and the pH remains high (above about 10). As a result of this long-term pozzolanic reaction, some soils can produce very high strength gains when lime treated. very substantial improvements in shear strength (by a factor of 20 or more in some cases), continued strength gain with time even after periods of environmental or load damage (autogenously healing) and long-term durability over decades of service even under severe environmental conditions.

1.5. Issues for the Millennium

Current ash generation in India is about 112 million metric tons and its current utilization is only about 42 million metric tons (38% of ash generated). Rest of the unutilized ash is being disposed off on to the ash ponds. Disposal of this enormous amount of fly ash faces problem of huge land requirement, transportation, ash pond construction and maintenance. Also to meet the rising energy demand power generating industries in India growing rapidly. India shall continue to depend on coal as the prime source of energy. In India environmental issues became a major concern in the 21st century so the solid waste management for coal based thermal power plants shall continue to be a major area of priority.

In developing country like India where the problems like increasing population, scarce natural resources specially land, increasing urbanization and energy requirements goes side by side with the development, it is almost impossible for power generation sector to function in isolation. So now a day's use of resource material like Fly ash became a major area of research. The past years have witnessed a significant growth in the technological level with respect to fly ash disposal & utilization in the country and in the next millennium fly ash in itself is going to emerge as a major industry.

1.6. Use of Fly ash

Some of the application areas of Fly ash are given below.

- Manufacture of Portland cement.
- Embankments and structural fill.
- Waste stabilization and solidification.
- Mine reclamation.
- Stabilization of soft soils.
- Road sub base.
- Manufacture of bricks
- Aggregate.
- Flow able fill.
- Mineral filler in asphaltic concrete.
- Application on rivers to melt ice.
- Used as a sub-base product in pavement design.
- Other applications include cellular concrete, geo polymers, & roofing tiles

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

India has a total installed capacity of 100,000 MW of electricity generation. Seventy-three percent of this is based on thermal power generation. The coal reserves of India are estimated around 200 billion metric tons. Because of this, 90% of the Indian thermal power stations are coal based. There are 85 coal based thermal power stations and other power stations in the country. The Indian coal has a low calorific value of 3,000–4,000 kcal/kg and a high ash content of 35–50%. To achieve the required energy production, a high coal fired rate is required, generating greater ash residue. Presently, India produces nearly 100 million metric tons of coal ash; that is expected to double in the next 10 years. The most common method adopted in India for the disposal of coal ashes is the wet method. This method requires, apart from a large capital investment, about 1 acre of land for every 1 MW of installed capacity. Thus, ash ponds occupy nearly 26,300 ha of land in India. The utilization of fly ash was just 3% in 1994, but there is a growing realization about the need for conservation of the environment in India. In 1994, the Government of India commissioned a Fly Ash Mission (FAM) with the broad objective of building confidence among the producer and consumer agencies in the safe disposal and utilization of fly ash, through technology demonstration projects. The FAM has chosen 10 major areas and so far has undertaken 55 technology demonstration projects at 21 locations across India. The fly ash utilization has increased from 3% in 1994 to 13% in 2002. A notification issued by the Ministry of Environment and Forests of the Government of India (MOEF 1999) on September 14, 1999, established the basic framework for the advancement of fly ash utilization and environment conservation efforts in the country. This notification required the existing thermal power plants to achieve 20% utilization of fly ash within 3 years and 100% utilization within 15 years. Newly commissioned plants are required to achieve 30% utilization of fly ash within 3 years and 100% utilization within 9 years. One of the common applications in which fly ash is used in large quantities is the construction of compacted fills and embankments. The Electric Power Research Institute's (EPRI) manual (Glogowski et al. 1992) reports that a project search conducted in 1984 located 33 embankments and 31 area fills in North America that were constructed with fly ash. According to the American Coal Ash Association (ACAA 1999), in 1999 about 33% of the fly ash as well as the bottom ash produced in the United States was used in different applications. The use of fly ash in structural fills was the second major application (5.1%) next to its use in cement, concrete, and grout (16.1%). Based on a survey of nine thermal power stations, Porbaha et al. (2000) estimated that in Japan about 41% of fly ash is used in the construction of landfills. Considering the major role that the construction of embankments and fills plays in the utilization of fly ash, the Fly Ash Mission in India has adopted this as one of the 10 major areas for technology demonstration projects. Already a few embankments have been constructed in India using pond ash (Vittal 2001). Recently, the Indian Road Congress has also published guidelines for the use of fly ash in road embankments (IRC 2001) [17].

Fly ash became an attractive construction material because of its self hardening characteristics for which available free lime is responsible. The variation of its properties depends upon the nature of coal, fineness of pulverization, type of furnace and firing temperature.

2.2 Literature on Fly ash and Pond ash

Various researchers have worked on the properties of fly ash and pond ash to judge their suitability as a construction material in various field of civil Engineering. Some of are summarized below.

Sherwood and Ryley (1970) reported that the fraction of lime, present as free lime in the form of calcium oxide or calcium hydroxide, controls self-hardening characteristics of fly ashes.

Gray and Lin (1972) have studied the variation of specific gravity of the coal ash and showed that the variation is the result of combination of many factors such as gradation, particle shape and chemical composition.

Mclaren and Digioia(1987) showed that because of the generally low value for the specific gravity of coal ash compared to soils, ash fills tend to result in low dry densities which is of advantage in the case of its use as a backfill material for retaining walls, embankments especially on weak foundation soils, reclamation of low-lying areas, etc. since the pressure exerted on the foundation structure will be less.

Mitchell (1981), Brown(1996) and Consoli et al (2001) soil–fly ash–lime shows a complex behavior that is affected by many factors, such as the physical-chemical properties of the soil–fly ash, the porosity, and the amount of lime at the time of compaction.

Martinet al. (1990) state that fly ash in a moist but unsaturated condition displays an apparent cohesion due to tensile stress of retained capillary water but this cannot be relied upon for long-term stability and conclude that for the strength property major interest is the angle of shearing resistance.

Indraratna et al. (1991) compared cohesion intercept and angle of shearing resistance of saturated and unsaturated fresh fly ash specimens and reported complete loss of cohesion owing to full saturation and no change in the angle of shearing resistance.

Yudbir and Honjo (1991) find that the free lime content of fly ash contributes to self hardening. Some fly ashes may achieve unconfined strength of the order 20 MN/m^2 in 28 days ,while other attain strength of order 0.1-0.4 MN/m^2 in 16 weeks., depending upon the availability of free lime and carbon contents in the samples.

Rajasekhar(1995) stated that coal ash comprises mostly glassy cenospheres and some solid spheres . The reason for a low specific gravity could either be due to the presence of large number of hollow cenospheres from which the entrapped air cannot be removed, or the variation in the chemical composition, in particular iron content, or both.

Singh (1996) studied the unconfined compressive strength of fly ashes as a function of free lime present in them.

Singh and Panda (1996) performed shear strength tests on freshly compacted fly ash specimens at various water contents and concluded that most of the shear strength is due to internal friction.

Pandian and Balasubramonian (1999) showed that co-efficient of permeability of ash depend upon the grain size ,degree of compaction and pozzolanic activity The bottom and pond ashes being coarse grained and devoid of fines compared to fly ash have a higher value for permeability coefficient. The consolidation pressure has negligible effect on the permeability.

Erdal Cokca (2001) has showed that Fly ash consists of often hollow sphere of silicon, alluminium and iron oxides and unoxidised carbon. Fly ash is pozzolans which are defined as siliceous and aluminous materials. Thus Fly ash can provide an array of divalent and trivalent cations like Ca^{+2}, Al^{+3}, Fe^{+3} etc under ionized condition that can promote flocculation of dispersed clay particles. Thus expansive soil can be potentially stabilized effectively by cation exchange using Fly ash.

Ghosh and Subbarao(2001) have studied the Scanning electron micrographs of modified fly ash specimen and show that the addition of lime to fly ash produces a compact matrix and that a long curing period is necessary to achieve more compact structures. The formation of a densified interlocking network of reaction products is prominent for the mixes containing gypsum, cured for 10 months at 307C. The Ca:Si ratio obtained from the EDAX analysis varies from 1.690 to 0.224 depending on the mix proportions and curing period. This variation may be attributed to the formation of different hydration products. The compact matrix, mainly due to pozzolanic reaction products as observed in SEM micrographs for the specimens stabilized with high lime (10%) and gypsum (1%) and cured for a longer curing period, is responsible for high strength and durability. The permeability has reduced to 10^{-7} cm/s due to the reduction in interconnectivity of the pore channels of the hydration products. The strength of fly ash, stabilized with 10% lime and 1% gypsum, has reached a value of 6,307 kPa at 3 months' curing, i.e., 36.7 times the strength of untreated fly ash. Thus this modified material with improved engineering characteristics may find potential applications in different civil engineering fields.

Das and Yudhbir(2005) have studied that factor like lime content(Cao), iron content (Fe2O3), Loss of ignition , morphology, and mineralogy govern the geotechnical properties of fly ashes.

Bera et al. (2007) implemented on the effective utilization of pond ash, as foundation medium. A series of laboratory model tests have been carried out using square, rectangular and strip footings on pond ash. The effects of dry density, degree of saturation of pond ash, size and shape of footing on ultimate bearing capacity of shallow foundations are presented in this paper. Local shear failure of a square footing on pond ash at 37% moisture content (optimum moisture content) is observed up to the values of dry density 11.20 kN/m3 and general shear failure takes place at the values of dry density 11.48 kN/m3 and 11.70 kN/m3. Effects of degree of saturation on ultimate bearing capacity were studied. Experimental results show that degree of saturation significantly affects the ultimate bearing capacity of strip footing. The effect of footing length to width ratio (L/B), on increase in ultimate bearing capacity of pond ash, is insignificant for L/B $\geq$ 10 in case of rectangular footings. The effects of size of footing on ultimate bearing capacity for all shapes of footings viz., square, rectangular and strip footings are highlighted.

Jakka et al. (2010) studied carried on the strength and other geotechnical characteristics of pond ash samples, collected from inflow and outflow points of two ash ponds in India, are presented. Strength characteristics were investigated using consolidated drained (CD) and undrained (CU) triaxial tests with pore water pressure measurements, conducted on loose and compacted specimens of pond ash samples under different confining pressures. Ash samples from inflow point exhibited behaviour similar to sandy soils in many respects. They exhibited 38 higher strengths than reference material (Yamuna sand), though their specific gravity and compacted maximum dry densities are significantly lower than sands. Ash samples from outflow point exhibited significant differences in their properties and values, compared to samples from inflow point. Shear strength of the ash samples from outflow point are observed to be low, particularly in loose state where static liquefaction is observed.

Jakka et al. (2010) have studied that densities of compacted ash is lower than natural soil due to their low value of specific gravity and intraparticle voids.

2.3. Literature on lime stabilization on soil, Fly ash and Pond ash

Various researchers worked on the stabilization of fly ash and pond ash to improve its properties.

Bell (1996) indicates that with Increase in liquid limit and plasticity index lime has increased the plasticity of the soils treated with. This is suggested due to the action of hydroxyl ions modifying the water affinity of the soil particles. Besides, increase in lime content, beyond a certain limit, is found to have reduced the strength. It is postulated that since lime itself has neither appreciable friction nor cohesion, excess of lime reduces the strength. But soil-lime stabilization being dependent on several factors such as, soil type, its mineralogy, lime content, curing period etc.

Rajasekaran and Rao (2000). Apart from modifying the plasticity and swelling characteristics, lime can stabilize the soils through cementation giving rise to visible increase in strength and stiffness due to pozzolanic reactions and can significantly improve the long term performance of the stabilized soils.

Chand et al. (2007) presented the effects of lime stabilization on the strength and durability aspects of a class F pond ash, with a lime constituent as low as 1.12%, are reported. Lime contents of 10 and 14% were used, and the samples were cured at ambient temperature of around 30°C for curing periods of 28, 45, 90, and 180 days. Samples were subjected to unconfined compression tests as well as tests that are usually applied to rocks such as point load strength tests, rebound hammer tests, and slake durability tests. Unconfined compressive strength (UCS) values of 4.8 and 5.8 MPa and slake durability indices of 98 and 99% were achieved after 180 days of curing for samples stabilized with 10 and 14% lime, respectively. Good correlations, that are particularly suitable for stabilized materials of low density and low strength, have been derived for strength parameters obtained from UCS tests, point load strength tests, and Schmidt rebound hammer tests, and also between UCS and slake durability index.

Ghosh et al. (2010) presents the laboratory test results of a Class F pond ash alone and stabilized with varying percentages of lime (4, 6, and 10%) and PG (0.5, and 1.0), to study the suitability of stabilized pond ash for road base and sub-base construction. Standard and modified Proctor compaction tests have been conducted to reveal the compaction characteristics of the stabilized pond ash. Bearing ratio tests have been conducted on specimens, compacted at maximum dry density and optimum moisture content obtained from standard Proctor compaction tests, cured for 7, 28, and 45 days. Both un-soaked and soaked bearing ratio tests have been conducted. This paper highlights the influence of lime content, PG content, and curing period on the bearing ratio of stabilized pond ash. The empirical model has been developed to estimate the bearing ratio for the stabilized mixes through multiple regression analysis. Linear empirical relationship has been presented herein to estimate soaked bearing ratio from un-soaked bearing ratio of stabilized pond ash. The experimental results indicate that pond ash-lime-PG mixes have potential for applications as road base and sub base materials.

2.4. SCOPE OF PRESENT STUDY

Thus, through appraisal of the literature review it is observed that several attempts have already been made by researchers to study the effect of additive on stabilization of fly ash. However the researches on the strength aspect of lightly cemented fly ash upon lime stabilization are comparatively less. The experimental programme undertaken investigates:

- Effect of compactive energy on the MDD and OMC of virgin condition of raw fly ash and lime treated fly ash.
- The effect of compaction energy on shear parameters, unconfined compressive strength, CBR value and co-efficient of permeability of Fly ash and lime stabilized fly ash specimens.
- The effect of curing period on unconfined compressive strength and CBR values of lime treated fly ash.
- Effect of lime content on the strength aspect of lime treated fly ash.

Chapter 3

Experimental Work and Methodology

3.1. INTRODUCTION

Large scale utilization of fly ash in geotechnical constructions will reduce the problems faced by the thermal power plants for its disposal mostly because of its property closely related with the natural earth material. So assessment of the behavior fly ash at different condition is required before its use as a construction material in Civil engineering structure. Even through adequate substitute for full scale field tests are not available; tests at laboratory scale provide a measure to control many of the variable encountered in practice. The trends and behavior pattern observed in the laboratory tests can be used in understanding the performance of the structures in the field and may be used in formulating mathematical relationship to predict the behavior of field structures. Details of material used, sample preparation and testing procedure adopted have been outlined in this chapter.

3.2 MATERIAL USED

3.2.1 Fly ash

Fly ash was collected from the captive power plant (CPP-II) and BFS from the dump pad of Rourkela steel plant (RSP).The sample was screened through 2mm sieve to separate out the foreign and vegetative matters. The collected samples were mixed thoroughly to get the homogeneity and oven dried at the temperature of 105-110 degree. Then the Fly ash samples were stored in airtight container for subsequent use.

3.2.2. Lime

Lime (Calcium Oxide CaO) used in this study was first sieved through 150 micron sieve and stored in airtight container for subsequent use.

3.3. SAMPLE PREPARATION AND EXPERIMENTAL PROGRAM

Four different lime contents, i.e.1%, 2%, 5% and 10%, were used for preparing stabilized fly ash samples. These lime content were chosen considering the very low lime content of the fly ash used in the present work.

The overall testing program is conducted in two phase. In first phase the geotechnical characteristics of the Fly ash samples were studied by conducting Hydrometer analysis, UCS test, Permeability test and CBR test. The overall testing program is outline in Table 3.1.

Table3 .1 Test program for lime stabilization of Fly ash

Sl. No.	Test Method	Complying standards	Samples Variable		Parameters
			% of Lime	Curing period (Days)	
1.	Proctor Test	IS:2720(Part-VII)-1987 and IS:2720(Part VIII)-1987	0,1,2,5,10	immediate	OMC,MMD
2	UCS test	IS:2720(Part-X)-1991	0,1,2,5,10	0,3,7,28,90	UCS
3.	CBR test	IS:2720(Part-XVI)-1987	0,1,2,5,10	28	CBR
4.	Permeability test	IS:2720(Part-XVII)-1986	0,1,2,5,10	28	Coefficient of Permeability

In second phase of the fly ash mixed with 1%, 2%,5% and 10% of lime. Lime added in percentage of dry weight of fly ash. The geotechnical property of this lime stabilized fly ash sample were evaluated and compared with that of fly ash.

To simulate the actual ash pond condition fly ash and lime stabilized fly ash was mixed with sufficient amount of water and the ash slurry was allowed to settle in a mould without any drainage arrangement. Loads of approximately 22 kPa and 55 kPa were placed over the sample to simulate an ash pond condition with an overburden surcharge ash pond of height 2m and 5m respectively.

Samples were collected at time intervals of 28 days and 90 days. The samples collected from stabilized and unstabilized ash bed were subjected to various tests to study the improvement in the geotechnical properties. The entire experimental investigation was conducted at an ambient temperature of around 33^0 C.

3.4. Physical property of Fly ash

The physical property of fly ash was determined and is presented in the Table 3.2.

Table3.2: Physical property of Fly ash

Physical Parameters	Value	Physical parameters	Value
Colour	Light grey	Shape	Rounded/sub rounded
Silt and Clay (%)	87	Coefficient of uniformity ,C_u	5.88
Fine Sand (%)	13	Coefficient of Curvature ,Cc	1.55
Medium Sand (%)	0	Specific Gravity, G	2.55
Coarse Sand (%)	0	Plasticity index	Non-plastic

The morphology of fly ash was studied by Scanning Electron microscope which shown in figure 3.1.This analysis show that fly ash mainly contain spherical size particle and have uniform gradation.

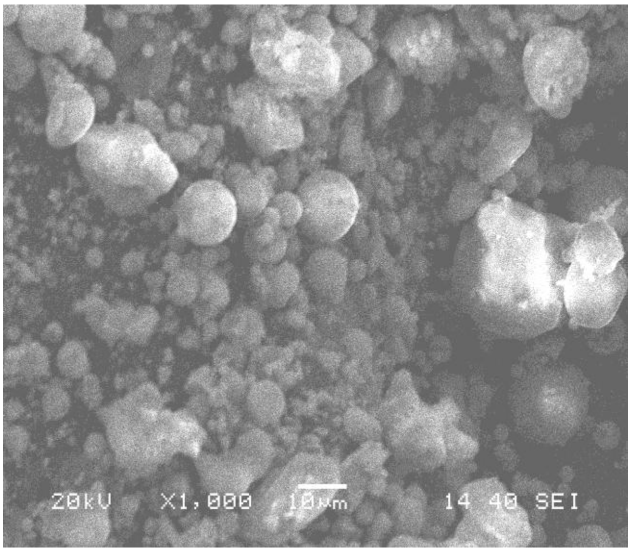

Figure 3.1: Scanning Electron Micrograph (SEM) of Fly ash

3.5. Chemical Composition of Fly ash

The chemical composition of fly ash was determined by XRD analysis and it shows that the fly ash merely consists of Alluminium oxide, Sillicon oxide etc. The XRD analysis result shown in figure 3.2.

Table 3.3 Chemical composition of fly ash

Elements	MgO	Al_2O_3	SiO_2	K_2O	P_2O_5	CaO	Fe_2O_3	Na_2O	MnO	TiO_2	SO_3	LOI
Composition (%)	0.57	24.12	52.55	0.965	0.72	2.65	-	-	-	-	-	18.18

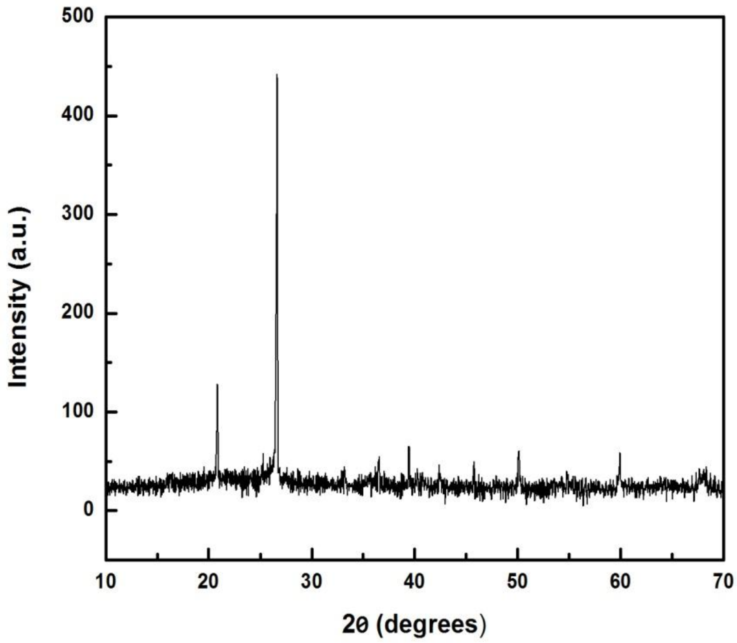

Figure 3.2 XRD analysis of fly ash

3.6. DETERMINATION OF INDEX PROPERTIES

3.6.1. Determination of Specific Gravity

The specific gravity of fly ash was determined according to IS: 2720 (Part-III/sec-1) 1980. The specific gravity of Fly ash was found to be 2.55. However the Specific gravity of Lime treated fly ash was determined by using Le-Chatelier flask with Kerosene as the solvent. The specific gravity of various lime-fly ash mixes are listed in the Table 3.4.

Table 3.4 Specific Gravity of Lime-Fly ash mix

Samples	Specific Gravity
FA+1% L	2.56
FA+2% L	2.59
FA+5% L	2.6
FA+10% L	2.66

3.6.2. Determination of Grain Size Distribution

For determination of grain size distribution, the fly ash was passed through test sieve having an opening size 75µ. Sieve analysis was conducted for coarser particles and hydrometer analysis was conducted for finer particles as per IS: 2720 (part IV)-1975. The percentage of fly ash passing through 75µ sieve was found to be 86.62%. Hence the particle size of fly ash ranges from fine sand to silt size. Coefficient of uniformity (C_u) and coefficient of curvature (C_c) for fly ash was found to be 5.88 & 1.55 respectively, indicating uniform gradation of samples. The grain size distribution curve of fly ash is presented in Fig 4.1.

3.7. DETERMINATION OF ENGINEERING PROPERTIES

3.7.1. Moisture Content Dry Density Relationship

The compaction characteristics of fly ash was found by using compaction tests as per IS: 2720 (Part VII) -1980 and IS: 2720 (Part VIII)-1980.Fly ash was stabilized with varying percentage of lime. The lime content was 0%, 1%, 2%, 5%, and 10% of the dry weight of Fly ash. For this test, samples were mixed with required amount of water and the wet sample was compacted in proctor mould either in three or five equal layers using standard proctor rammer of 2.6 kg or modified proctor rammer of 4.5 kg. The moisture content of the compacted mixture was determined as per IS: 2720 (Part II) 1973. From the dry density and moisture content relationship, optimum moisture content (OMC) and maximum dry density (MDD) were determined. Similar compaction tests were conducted with varying compactive energy and the corresponding OMC and MDD were determined. This was done to study the effect of compactive energy on OMC and MDD. The compactive energies used in this test programme were 118.6, 355.8,593 and 2483 kJ/m^3 of compacted volume. The test results are presented in Table 3.5.

Table 3.5: Compaction characteristics Fly ash with different compactive effort

Samples	118.6 kJ/m^3		355.6 kJ/m^3		593 kJ/m^3		2483 kJ/m^3	
	MDD (gm/cc)	OMC (%)	MDD (gm/cc)	OMC (%)	MDD (gm/cc)	OMC (%)	MDD (gm/cc)	OMC (%)
Fly ash	1.142	31.2	1.184	27.6	1.2	27	1.255	24.2

Table 3.6: Compaction characteristics Lime- Fly ash mix with different compactive effort

Sl. No.	Lime Content (%)	118.6 kJ/m^3		355.6 kJ/m^3		593 kJ/m^3		2483 kJ/m^3	
		OMC (%)	MDD (gm/cc)	OMC (%)	MDD (gm/cc)	OMC (%)	MDD (gm/cc)	OMC (%)	MDD (gm/cc)
1.	1	30	1.153	27	1.204	25.8	1.208	23.1	1.278
2.	2	29.4	1.16	25.2	1.218	24.2	1.221	22.5	1.29
3.	5	28.5	1.162	25.7	1.219	23.5	1.248	20.4	1.316
4.	10	27.6	1.168	23.4	1.28	22.8	1.26	19.5	1.365

3.7.2. Determination of Unconfined Compressive Strength

The Unconfined compressive strength test is one of the common tests used to study the strength characteristics of soil and stabilized soil. To get Immediate UCS strength, UCS tests on fly ash and lime stabilized fly ash specimens compacted to their corresponding MDD at OMC with compactive effort varying as 118.6, 355.6, 593, 2483, kJ/m3 were performed according to IS: 2720 (Part X)-1991. For this test cylindrical specimens were prepared corresponding to their MDD at OMC in the metallic split mould with dimension 50mm (dia.) × 100mm (high). These specimens were tested in a compression testing machine with strain rate of 1.25% per minute till failure of the sample.

To determined the effect of curing period on strength property all samples were coated with wax and cured in a humidity camber at an average temperature of 33º C for a period of 3,7,28 and 90 days before testing.

Figure 3.3: Lime stabilized fly ash coated with Wax

Figure 3.4: UCS test on wax coated Lime treated fly ash

The unconfined compressive strengths of specimens were determined from stress versus strain curves plots and the unconfined strength and corresponding failure strain at different compactive energy after 0, 3.7,28,90 Days of curing is given in Table 3.7.

Table 3.7: Immediate Unconfined compressive strength of Fly ash and Lime-Fly ash mix at different compactive energy

Lime content (%)	Compactive Energy								
	355.8 kJ/m³			593 kJ/m³			2483 kJ/m³		
	Faliure Strain (%)	UCS (kPa)	NUCS (kPa)	Faliure Strain (%)	UCS (kPa	NUCS (kPa)	Faliure Strain (%)	UCS (kPa	NUCS (kPa)
0	1.75	32.764	1	1.5	44.353	1	1.25	47.271	1
1	2	52.972	1.617	1.75	62.44	1.408	1.5	83.08	1.758
2	2	55.3	1.688	1.75	68.45	1.543	1.5	84.62	1.79
5	2	57.629	1.759	2	86.15	1.942	2	100.7	2.13
10	2	89.873	2743	2	203.78	4.594	1.75	345.293	7.304

Table 3.8: Unconfined compressive strength of Fly ash and Lime-Fly ash mix at different compactive energy after 3 days of curing

Lime content (%)	Compactive Energy								
	355.8 kJ/m³			593 kJ/m³			2483 kJ/m³		
	Faliure Strain (%)	UCS (kPa)	NUCS (kPa)	Faliure Strain (%)	UCS (kPa	NUCS (kPa)	Faliure Strain (%)	UCS (kPa	NUCS (kPa)
0	1.5	36.86	1	1.5	46.806	1	1.5	50.317	1
1	1.5	61.433	1.67	1.5	85.42	1.825	1.75	130.14	2.586
2	1.75	100.378	2.723	2.25	112.64	2.407	2	153.09	3.043
5	2	130.019	3.527	2.5	210.44	4.496	2.25	275.22	5.47
10	2	224.694	6.096	1.5	307.23	6.564	1.5	372.657	7.406

Table 3.9: Unconfined compressive strength of Lime treated Fly ash at different compactive energy after 7 day of curing.

Lime content (%)	Compactive Energy								
	355.8 kJ/m³			593 kJ/m³			2483 kJ/m³		
	Faliure Strain (%)	UCS (kPa)	NUCS (kPa)	Faliure Strain (%)	UCS (kPa	NUCS (kPa)	Faliure Strain (%)	UCS (kPa	NUCS (kPa)
0	1.5	39.2	1	1.25	50.444	1	1.5	61.433	1
1	1.75	90.457	2.308	2	129.23	2.562	2	148.44	2.416
2	1.75	117.886	3.007	2	149.02	2.954	2	216.45	3.523
5	2	186.677	4.762	2	261.95	5.193	2.5	383.97	6.25
10	2	325.981	8.316	1.25	406.40	8.056	1.25	553.457	9.009

Table 3.10: Unconfined compressive strength of Lime treated Fly ash at different compactive energy after 28 Days of curing.

Lime content (%)	Compactive Energy								
	355.8 kJ/m³			593 kJ/m³			2483 kJ/m³		
	Faliure Strain (%)	UCS (kPa)	NUCS (kPa)	Faliure Strain (%)	UCS (kPa	NUCS (kPa)	Faliure Strain (%)	UCS (kPa	NUCS (kPa)
0	1.75	55.441	1	1.5	60.263	1	1.5	70.209	1
1	1.75	174.495	3.147	2.25	142.83	2.37	2	184.53	2.628
2	2	196.171	3.538	2.5	217.76	3.613	2.25	304.31	4.33
5	1	292.043	5.268	1.75	435.55	7.227	2.25	614.01	8.745
10	1.75	493.279	8.897	2.75	810.283	13.446	2.75	947.905	13.5

Table 3.11: Unconfined compressive strength of Lime treated Fly ash at different compactive energy after 90 Days of curing.

Lime content (%)	Compactive Energy								
	355.8 kJ/m³			593 kJ/m³			2483 kJ/m³		
	Faliure Strain (%)	UCS (kPa)	NUCS (kPa)	Faliure Strain (%)	UCS (kPa	NUCS (kPa)	Faliure Strain (%)	UCS (kPa	NUCS (kPa)
0	1.75	69.671	1	1.5	72.642	1	1.25	89.633	1
1	1.25	196.071	2.81	1.25	249.29	3.43	1.25	280.10	3.12
2	1.5	343.653	4.93	1.5	596.74	8.215	1.5	684.23	7.63
5	2	924.25	1327	2.25	1759.5	24.22	1.75	2208.15	24.64
10	2	1806.185	25.92	2	3572.07	49.17	2	4440.28	49.54

3.7.3. Determination of California Bearing Ratio

Bearing ratio is one of the vital parameters, used in the evaluation of soil sub grades for both rigid and flexible pavements design. It is also an integral part of several pavement thickness design methods. To assess the suitability of Fly ash and Fly ash stabilized with lime both unsoaked and soaked tests have been conducted. The CBR tests have been conducted in accordance with IS: 2720(Part XVI)-1987. For this test cylindrical specimens were prepared corresponding to their MDD at OMC in a rigid metallic cylinder mould with an inside diameter of 150 mm and a height of 175 mm. For this, Static compaction is done by keeping the mould assembly in compression machine and compacted the sample by pressing the displacer disc till the level of the disc reaches the top of the mould. The load was kept for some time, and then release. The displacer disc was removed .The mould with samples were tested in a CBR testing machine. A mechanical loading machine equipped with a movable base that moves at a uniform rate of 1.2 mm/min and a calibrated proving ring is used to record the load. The proving ring is attached with a piston, which penetrates into the compacted specimen. Diameter of the piston is 50 mm .The load was recorded carefully as function of penetration up to a penetration of 12.5 mm.

To study the effect of curing period the stabilized Fly ash samples with different percentage of lime (1%, 2%, 5%, 10%) were prepared at a MDD and OMC corresponding to the compaction energy of 118.6, 355.8, 593 and 2483 kJ/m^3.These samples were subjected to a curing period of 24 days following a soaking period of 4 days to study the effect of pozzolanic reaction of lime on CBR value of stabilized fly ash as shown in figure 3.5.

Fig 3.5: Lime treated fly ash sample subjected to 24 days of curing prior to 4 days of soaking

The Soaked and unsoaked CBR value of all samples at different compaction energy are given in the table 3.12, 3.13, 3.14 and 3.15.

Table 3.12: CBR test result of Fly ash and lime treated Fly ash at compaction energy of 118.6 kJ/m^3

Lime (%)	Unsoaked CBR value				Soaked CBR value			
	CBR value at 2.5 mm Penetr a-tion (%)	CBR value at 5 mm Penetr-ation (%)	Normalized CBR Values 2.5 mm Penetration (%)	Normalized CBR Values 5 mm Penetration (%)	CBR value at 2.5 mm Penetrati on (%)	CBR value at 5 mm Penetrati on (%)	Normalized CBR Values 2.5 mm Penetration (%)	Normalized CBR Values 5 mm Penetration (%)
0	5.83	5.65	1	1	0.59	0.57	1	1
1	13.88	10.61	2.38	1.88	0.817	0.795	1.385	1.395
2	13.51	12.89	2.317	2.281	0.93	0.88	1.576	1.544
5	15.72	14.62	2.696	2.587	3.003	2.915	5.089	5.11
10	24.69	23.46	4.235	4.152	6.62	6.36	11.22	11.158

Table 3.13: CBR test result of Fly ash and lime treated Fly ash at compaction energy of 355.8 kJ/m^3.

Lime (%)	Unsoaked CBR value				Soaked CBR value			
	CBR value at 2.5 mm Penetr-ation (%)	CBR value at 5 mm Penetr-ation (%)	Normalized CBR Values 2.5 mm Penetration (%)	Normalized CBR Values 5 mm Penetration (%)	CBR value at 2.5 mm Penetra-tion (%)	CBR value at 5 mm Penetrati-on (%)	Normalized CBR Values 2.5 mm Penetration (%)	Normalized CBR Values 5 mm Penetration (%)
0	7.51	6.86	1	1	0.75	0.71	1	1
1	18.05	17.26	2.403	2.516	1.457	1.398	1.943	1.969
2	20.25	20.11	2.696	2.931	1.501	1.472	2.001	2.073
5	25.95	25.06	3.455	3.653	3.93	3.886	5.24	5.473
10	31.75	30.88	4.228	4.501	11.25	11	15	15.492

Table 3.14: CBR test result of Fly ash and lime treated Fly ash at compaction energy of 593 kJ/m^3.

Lime (%)	Soaked CBR value				Unsoaked CBR value			
	CBR value at 2.5 mm Penetr at-ion (%)	CBR value at 5 mm Penetra-tion (%)	Normalized CBR Values 2.5 mm Penetration (%)	Normalized CBR Values 5 mm Penetration (%)	CBR value at 2.5 mm Penetrat ion (%)	CBR value at 5 mm Penetrati on (%)	Normalized CBR Values 2.5 mm Penetration (%)	Normalized CBR Values 5 mm Penetration (%)
0	18.41	17.96	1	1	1.15	1.09	1	1
1	22.02	21.34	1.196	1.188	1.89	1.734	1.643	1.591
2	24.01	22.25	1.304	1.239	2.032	2.019	1.767	1.852
5	27.45	27.26	1.491	1.518	4.938	4.836	4.294	4.437
10	32.63	31.47	1.772	1.752	12.7	12.58	11.04	11.54

Table 3.15: CBR test result of Fly ash and lime treated Fly ash at a compaction energy of 2483 kJ/m^3

Lime (%)	Soaked CBR value				Unsoaked CBR value			
	CBR value at 2.5 mm Penetration (%)	CBR value at 5 mm Penetration (%)	Normalized CBR Values 2.5 mm Penetration (%)	Normalized CBR Values 5 mm Penetration (%)	CBR value at 2.5 mm Penetration (%)	CBR value at 5 mm Penetration (%)	Normalized CBR Values 2.5 mm Penetration (%)	Normalized CBR Values 5 mm Penetration (%)
0	25.39	19.58	1	1	1.546	1.531	1	1
1	29.25	24.35	1.152	1.244	2.164	1.914	1.399	1.25
2	31.38	25.25	1.236	1.289	3.268	3.150	2.114	2.057
5	41.27	29.57	1.625	1.51	10.289	10.010	6.655	6.538
10	48.52	48.25	1.911	2.464	18.37	18.06	11.88	11.796

3.7.4. Determination of Shear Parameters

The shear parameters samples at their corresponding MDD and OMC were determined according to IS: 2720 (Part XIII) 1986.These samples were of size 60mm×60mm×25mm deep and sheared at a rate of 1.25 mm/minute. The shear strength parameters of the samples were determined from normal stress versus shear stress plots and it is given in Table 3.16.

Table3.16: Shear Parameter of Fly ash

Sample	Compaction Energy							
	118.6 kJ/m3		355.6 kJ/m3		593 kJ/m3		2483 kJ/m3	
	C_u (kN/m²)	Φ (º)	C_u (kN/m²)	Φ (º)	C_u (kN/m²)	Φ (º)	C_u (kN/m²)	Φ (º)
Fly ash	6	19.59	10.3	20.66	11.7	22.34	13.5	24.08

3.7.5. Determination of Permeability

Permeability (or hydraulic conductivity) refers to the ease with which water can flow through a soil. This property is essential for the calculation of seepage through earth dams or under sheet pile walls, the calculation of the seepage rate from waste storage facilities (landfills, ponds, etc.).

The permeability of fly ash is determined according to IS: 2720(Part XVII)-1986.However the Lime stabilized sample was subjected to a curing period of 28 days in a mould before the permeability test as shown in figure 3.6.

Figure 3.6: Lime treated samples cured for 28 days in permeability mould

The variation of co-efficient of permeability with the variation of lime content and compaction energy is listed in the Table 3.17.

Table3.17: Co-efficient of permeability of lime stabilized sample at different compaction energy

Sample	Coefficient of permeability at different compaction energy (cm/sec)			
	118.5 kJ/m^3	355.8 kJ/m^3	593 kJ/m^3	1434.7 kJ/m^3
FA	13.37×10^{-5}	12.92×10^{-5}	8.21×10^{-5}	7.65×10^{-5}
FA+1% L	13.45×10^{-5}	12.74×10^{-5}	6.96×10^{-5}	6.8×10^{-5}
FA+2% L	12.74×10^{-5}	9.44×10^{-5}	7.04×10^{-5}	6.32×10^{-5}
FA+5% L	7.49×10^{-5}	6.05×10^{-5}	4.66×10^{-5}	2.71×10^{-5}
FA+10 % L	3.58×10^{-5}	2.49×10^{-5}	0.98×10^{-5}	0.371×10^{-5}

CHAPTER 4

RESULT AND DISCUSSION

(GEOTECHNICAL PROPERTY OF FLY ASH)

4.1. INTRODUCTION

Basically Fly ash refers to the Fine ash particle suspended in the boiler furnace during lignite and sub-bituminous coal combustion. This material is solidified while suspended in exhausted and collected in the electrostatic precipitators. Since the particle solidify while suspended in the exhaust gases, Fly ash particle generally spherical in shape. Fly ash consists of inorganic matter present in the coal that has been fused during coal combustion [15]. A series of conventional laboratory tests such as light and heavy compaction tests, unconfined compressive strength tests, direct shear tests and CBR tests have been carried out on compacted fly ash. Test result are presented and discussed in this chapter.

4.2. INDEX PROPERTIES

4.2.1. Specific Gravity

Specific gravity is one of the important physical properties needed for the use of coal ashes for geotechnical and other applications. In general, the specific gravity of coal ashes lies around 2.0 but can vary to a large extent (1.6 to 3.1)[13]. The variation of specific gravity of the coal ash is the result of a combination of many factors such as gradation, particle shape and chemical composition. The reason for a low specific gravity could either be due to the presence of large number of hollow cenospheres from which the entrapped micro bubbles of air cannot be removed, or the variation in the chemical composition, in particular iron content, or both [15].The specific gravity of Fly ash was determined according to IS: 2720 (Part-III) -1980 guidelines by Le-Chartelier method with kerosene oil. The average specific gravity value found to be 2.55. The specific gravity of Fly ash was found to be lower than that of the conventional earth material.

4.2.2. Grain size

The particle size of Fly ash ranges from fine sand to silt size as shown in Fig. 4.1. The percentage of Fly ash passing through 75μ sieve was found to be 86.62%. The coefficient of uniformity (Cu) and coefficient of curvature (Cc) for Fly ash were found to be 5.88 & 1.55 respectively, indicating uniform gradation of samples. The grain size distribution mostly depends on degree of pulverization of coal and firing temperature in boiler units. The presence of foreign materials in fly ash also influences its grain size distribution. In ash pond the original particles undergoes flocculation and conglomeration resulting in an increase in particle size.

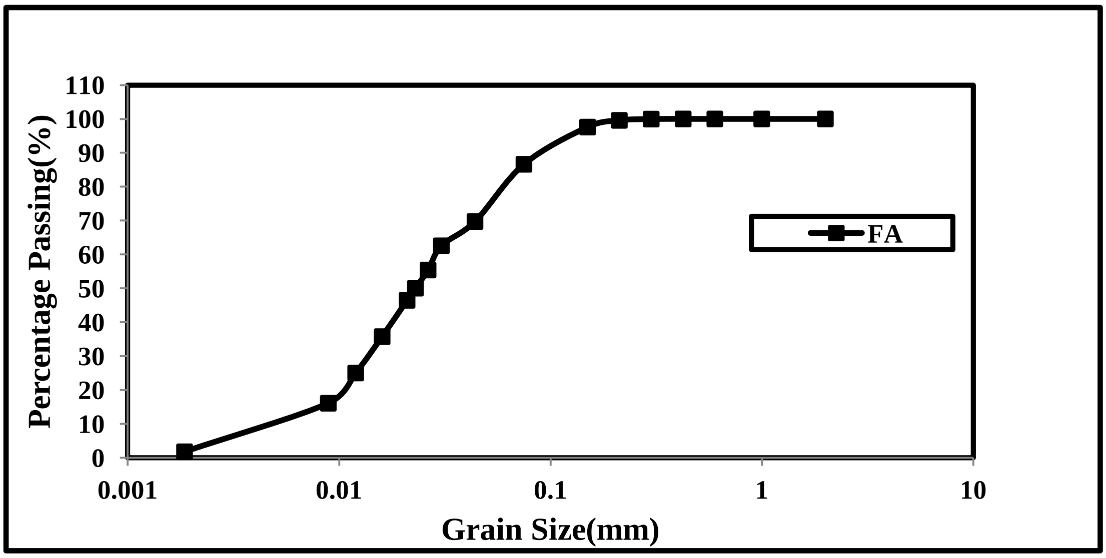

Figure 4.1: Grain size distribution curve of fly ash

4.3. ENGINEERING PROPERTIES

4.3.1. Compaction Characteristics

The compaction characteristics of fly ash with different compaction energies have been studied by varying the compaction energies as118.6, 355.8, 593, and 2483 kJ/m³ of compacted volume. The OMC and MDD of fly ash samples corresponding to these compactive efforts have been evaluated and presented in Table 3.6. Relationship between dry density and moisture content of fly ash at different compaction energies have been shown in Fig 4.2. It is seen that as the compactive energy increases the MDD increases and the water required to achieve this density is reduced. A continuous increase in the value of MDD is observed with the compactive energy (Fig.4.3). Plot between OMC and compactive energy (Fig.4.4) shows that initially the OMC decreases rapidly with compactive effort and then the rate of decrease is not that prominent .The MDD of specimens is found to change from 1.142 to 1.255kN/m3 with change in compaction energy from 118.6 to 3483kJ/m3 whereas the OMC is found to decrease from 30.2 to 24.2%. This shows that the compacted density of fly ash responds very poorly to the compaction energy. This may be attributed to the rounded shape of particles and uniform gradation of the sample. There are many factors like gradation, carbon content, iron content and fineness etc., mainly control the compaction characteristics of fly ash.

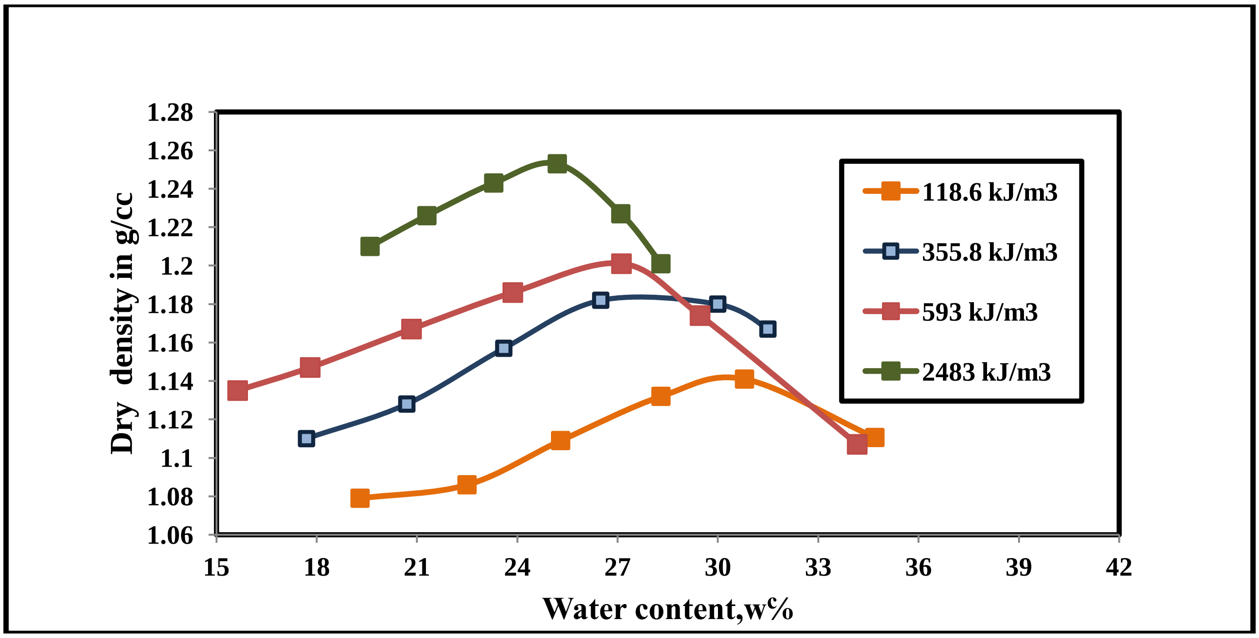

Fig 4.2: Compaction curve of Fly ash at different compaction energy

Te variation of MDD with the compaction energy is shown in figure 4.3.With increase in compaction energy MDD increases. A linear relationship between MDD and compaction energy is found after compaction energy of 355.6 kJ/m^3.

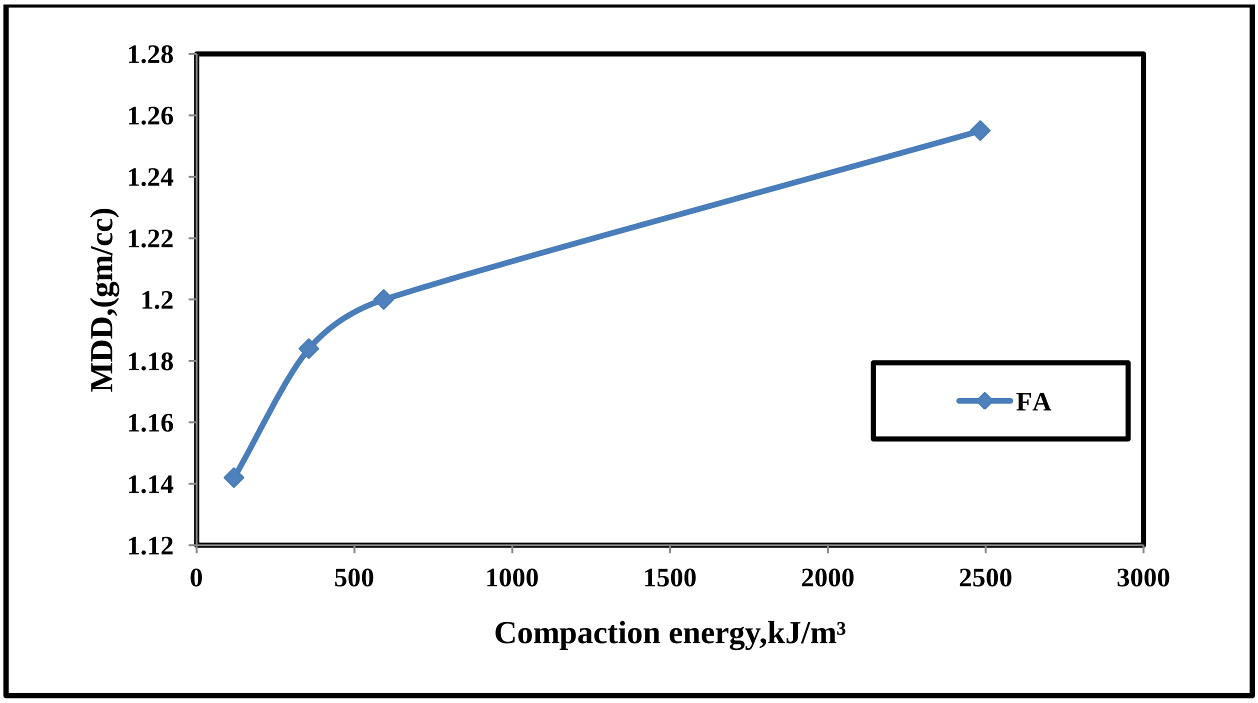

Fig 4.3: Variation of MDD of Fly ash at different compaction energy

The variation of OMC with compaction energy is shown in figure 4.4.OMC decreases with increase in compaction energy.

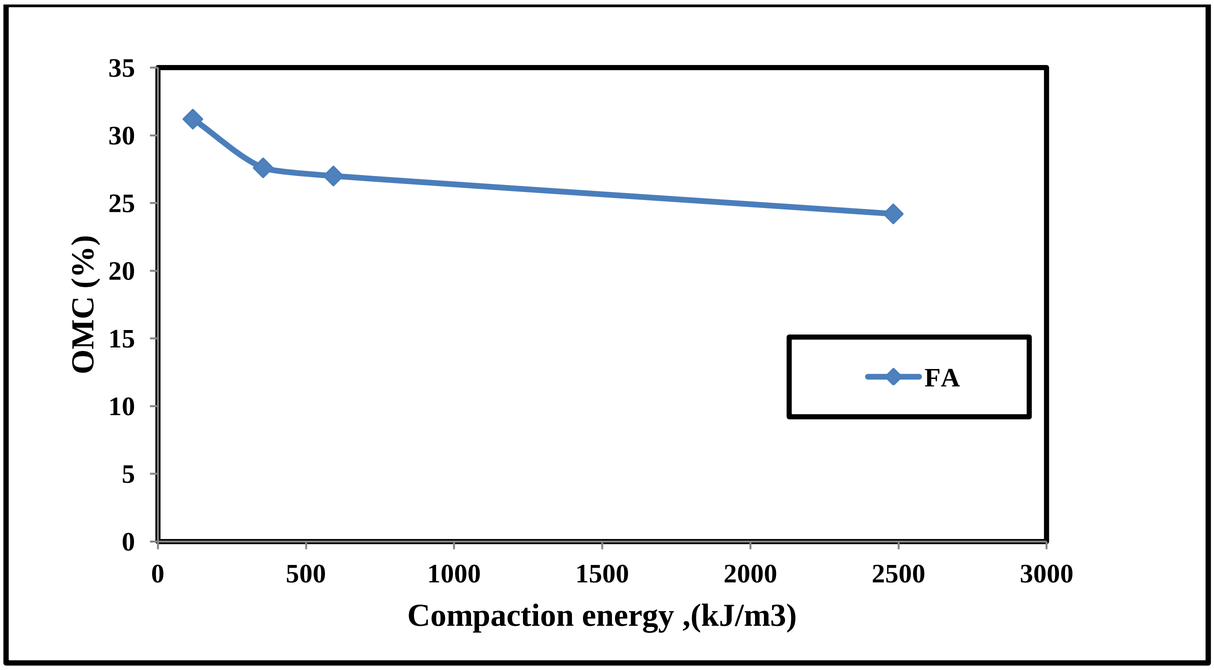

Fig 4.4: Variation of OMC of Fly ash at different compaction energy

4.3.2. Determination of Unconfined Compressive Strength

4.3.2.1. Effect of Compaction Energy

Unconfined compressive strength tests were carried out on untreated fly ash specimens compacted to their corresponding MDD at OMC with compactive effort varying as 355.8, 593 and 2483kJ/m3. The stress-strain relationships of compacted fly ash were presented in Fig.4.5. Form these plots it is observed that the failure stress as well as initial stiffness of samples, compacted with greater compaction energy, are higher than the samples compacted with lower compaction energy. The immediate compressive strength of fly ash is 32.674 kPa at compaction energy of 355.8 kJ/m^3 which increase to 47.271kPa at compaction energy of 2483kJ/m^3.However in general the failure strains are found to be lower for samples compacted with higher energies. The failure strains vary from a value of 1.5 to 1.75%, indicating brittle failures in the specimens. The increase in unconfined strength and initial stiffness of specimens with increased compactive effort is attributed to the closer packing of particles, resulting in the increased interlocking among particles. A closer packing is also responsible in increasing the cohesion component in the sample

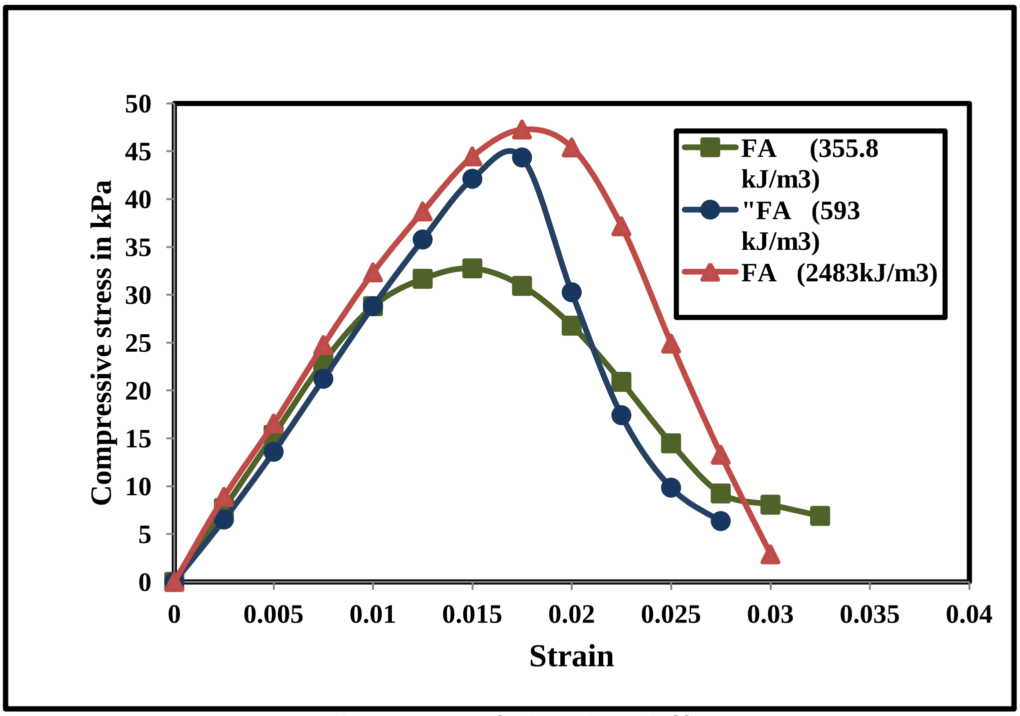

Figure 4.5: Stress-strain relationship of Fly ash at different compaction energy

Variation of unconfined compressive strength with compaction energy is shown in figure 4.6. . A nonlinear relationship is found to exist up to 593 kJ/m³ of compaction energy then it increases linearly with the compactive effort.

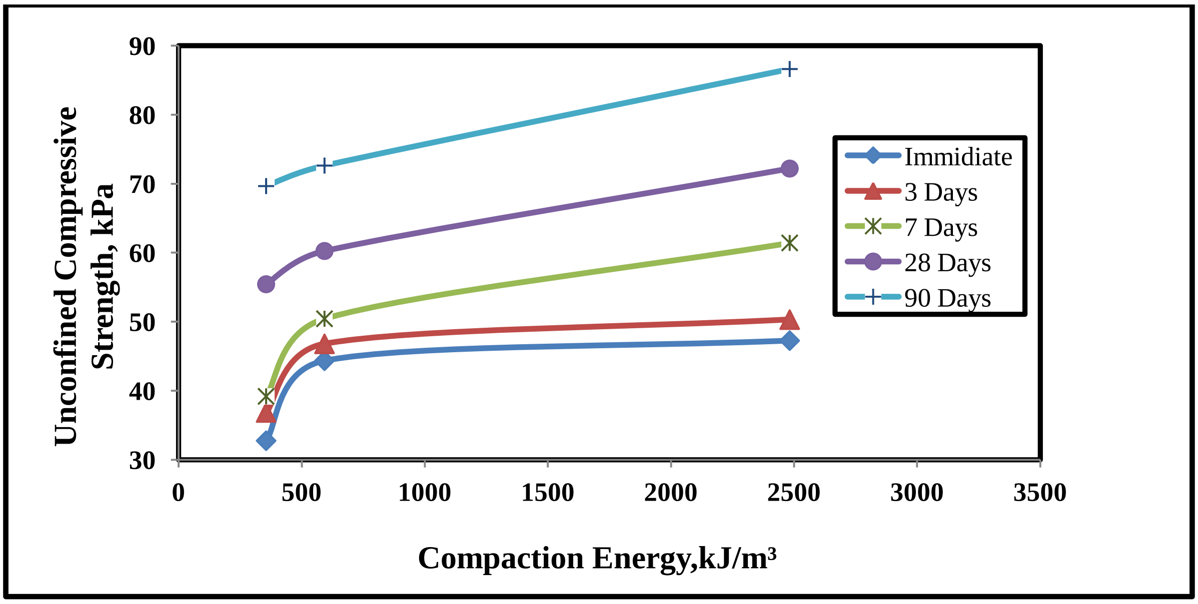

Figure 4.6: Variation of Unconfined compressive strength with Compactive energy at different curing period

Deformation modulus is one of the important parameter in the design of Pavement. It is a key factor for estimating settlement of foundation resting on fly ash fill or embankment made of compacted fly ash. The variation of deformation modulus as a function of unconfined compressive strength is generally required for design process. The relationships of deformation modulus as a function of UCS are shown in Figure 4.7.

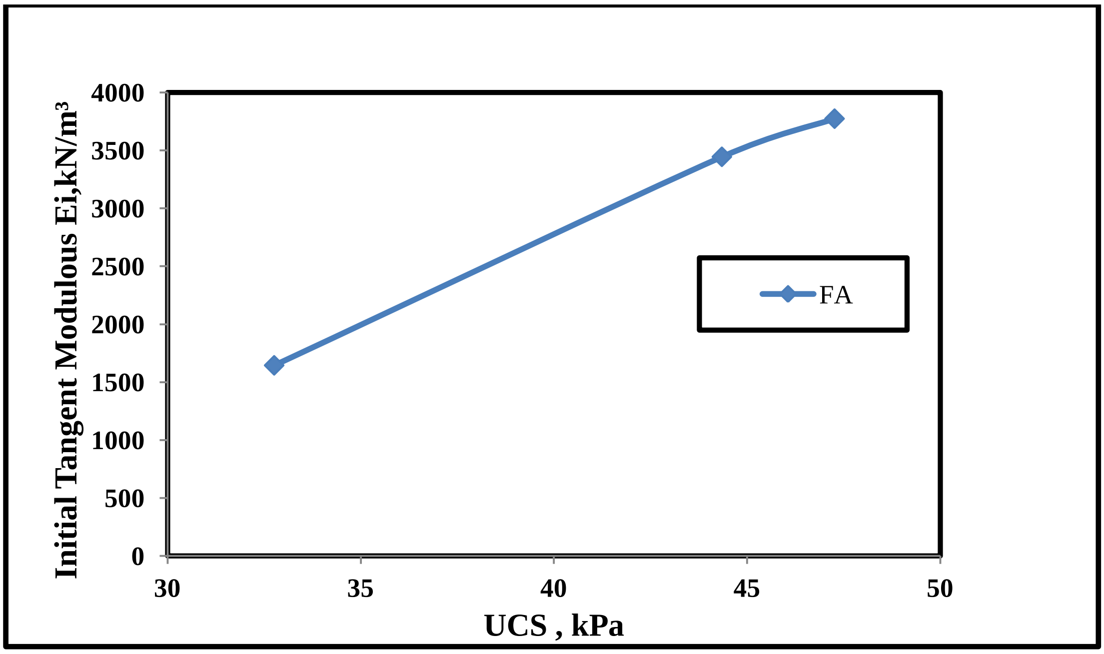

Figure 4.7: Variation of Initial tangent modulus with unconfined compressive strength of fly ash

With increase in UCS value initial tangent modulus increases as result of which stiffness of the sample increases. A linear relationship exists between Initial tangent modulus and UCS value.

Increase in compaction energy result in increase in initial tangent modulus as higher compaction leads to closer packing of particles. Variation of initial tangent modulus with the compaction energy is shown in figure 4.8.

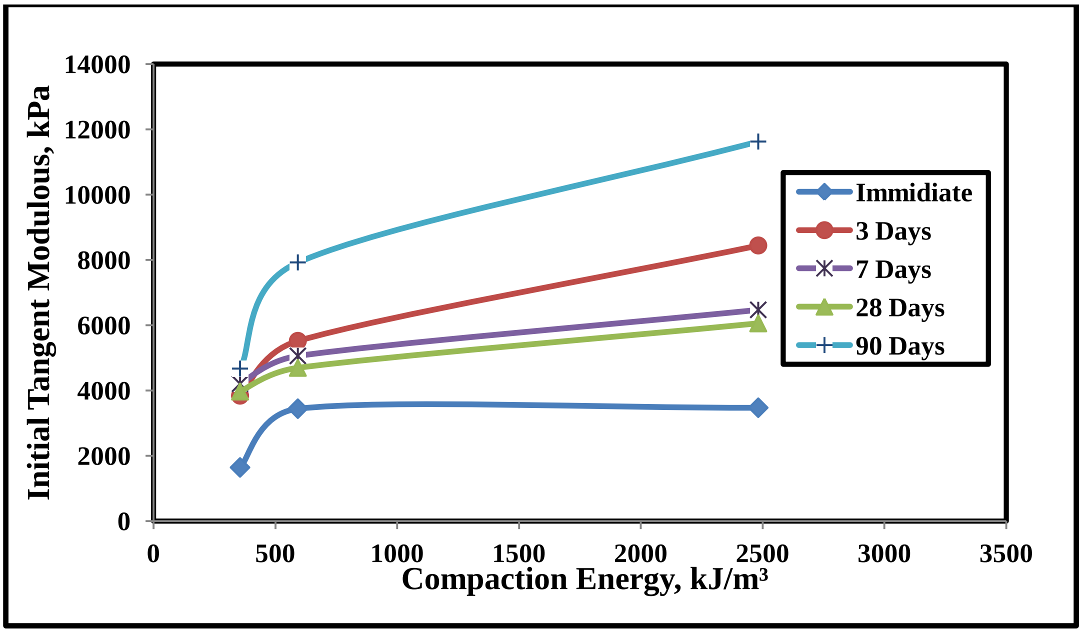

Figure 4.8: Variation of Initial tangent modulus Fly ash with the compaction energy

4.3.2.2. Effect of curing period

The unconfined compressive strength increases with increase in curing period. Increase in 3 days cured strength is not so remarkable. At a compaction energy of 355.8 kJ/m³ the 7 days strength is very low with only 39.2 kPa. The compressive strength increases up to 55.441kPa, 69.671kPa after 28 and 90 days respectively. However at a compacted energy of 593 kJ/m³, the compressive strength increases from 44.353 kJ/m³to 72.642 kJ/m³ after 90 days of curing. With further increase in compaction energy of 2483 kJ/m³, the UCS value increases up to 89.633 kPa. Compressive strength is basically function of free lime present in the sample.There is a marginal increase in compressive strength of fly ash with increase in curing period, which can be substantially improved with additives like lime. The Stress-strain curve of fly ash at compaction energy of 355.8 kJ/m³, 593kJ/m³ and 2483 kJ/m³ at different curing period is shown in figure 4.9, 4.10 and 4.11 respectively.

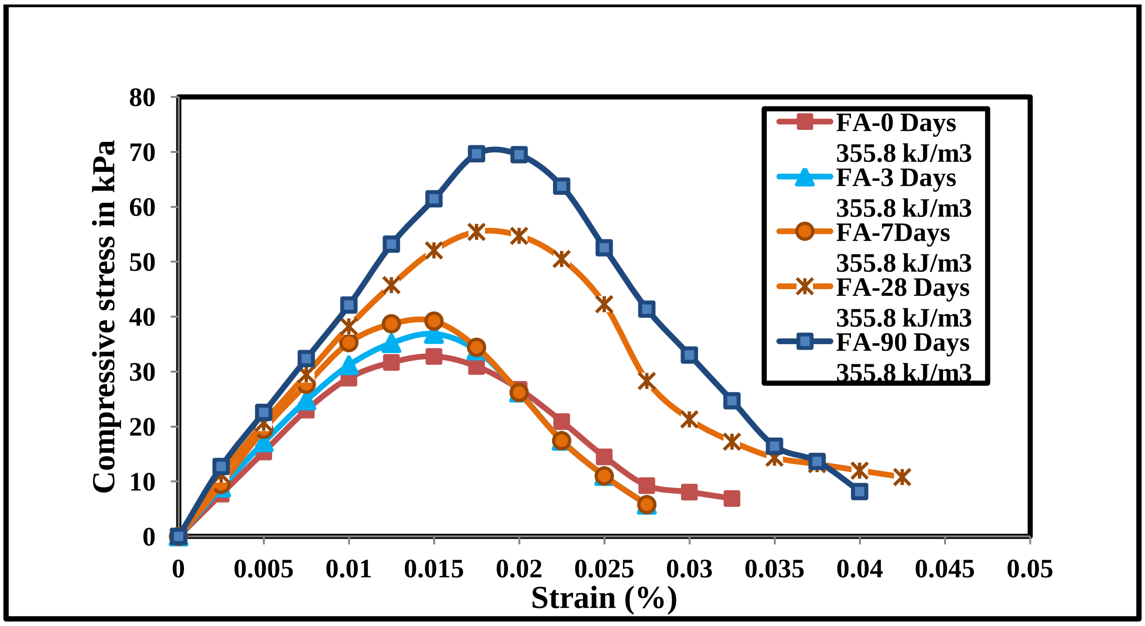

Figure 4.9: Stress-strain curve of Fly ash at compaction energy of 355.8 kJ/m³ at different curing period

With increase in curing period compressive strength increases. This is due to available free lime present in the fly ash sample which subsequently react with fly ash to form cementitious product that result in increase in strength. This increasing trend is more effective with increase in compaction energy. The stress-strain curve at higher compaction energy of 593 kJ/m^3 and 2483 kJ/m^3 are shown in figure 4.10 and 4.11.

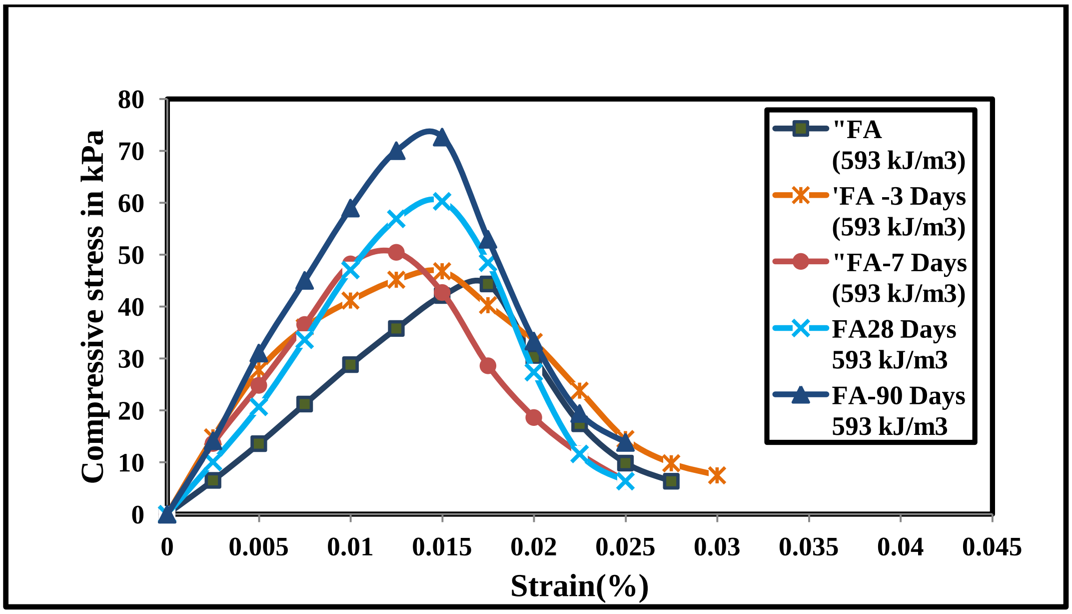

Figure 4.10: Stress-strain curve of Fly ash at compaction energy of 593 kJ/m³ at different curing period

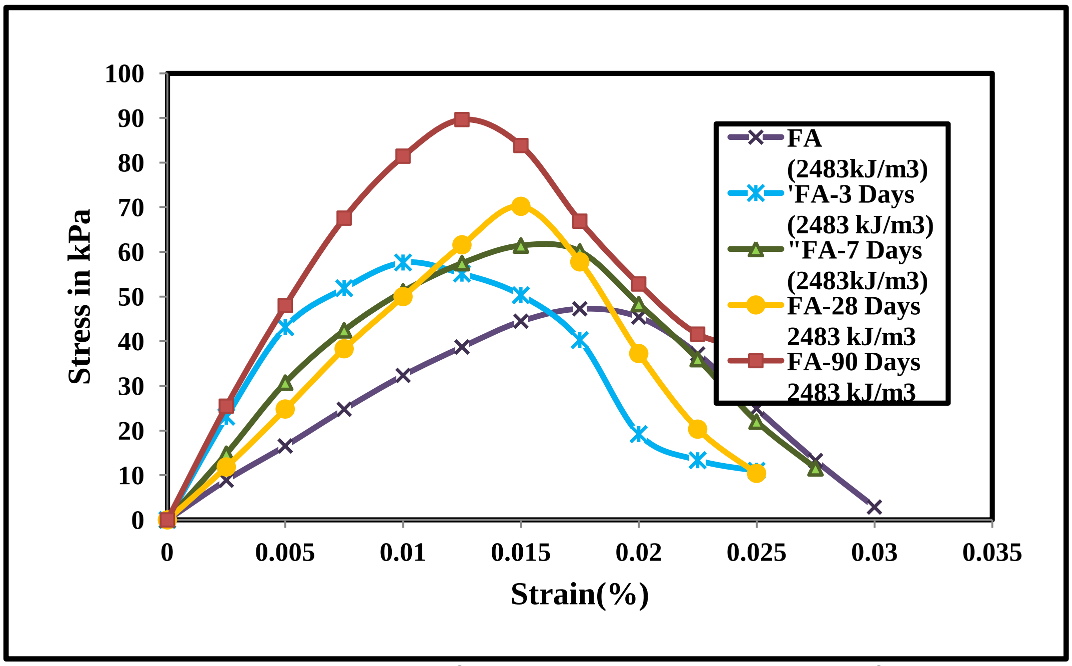

Figure 4.11: Stress-strain curve of Fly ash at compaction energy of 2483 kJ/m³ at different curing period

The variation of unconfined compressive strength with the curing period at different compaction energy is shown in Figure 4.12.There is a linear relationship exist between unconfined strength

and curing period.

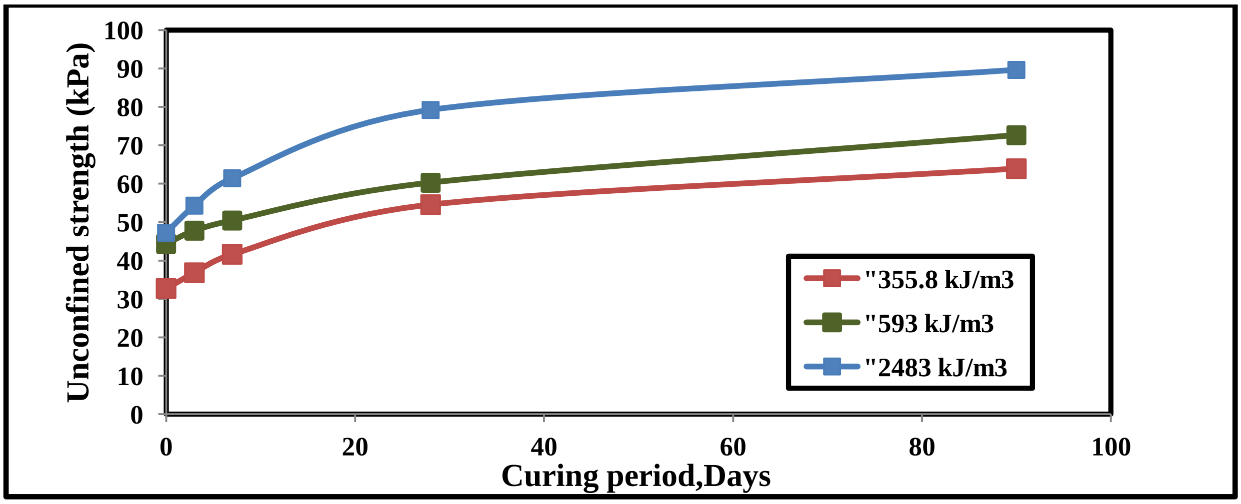

Figure 4.12: Variation of unconfined compressive strength with the curing period at different compaction energy

The graph showing the variation of initial tangent modulus with the curing period is shown in figure 4.13. The Initial tangent modulus generally increases linearly after the compaction energy of 593 kJ/m^3, which indicate a dramatic improvement of stiffness after the compactive energy of 593 kJ/m^3.

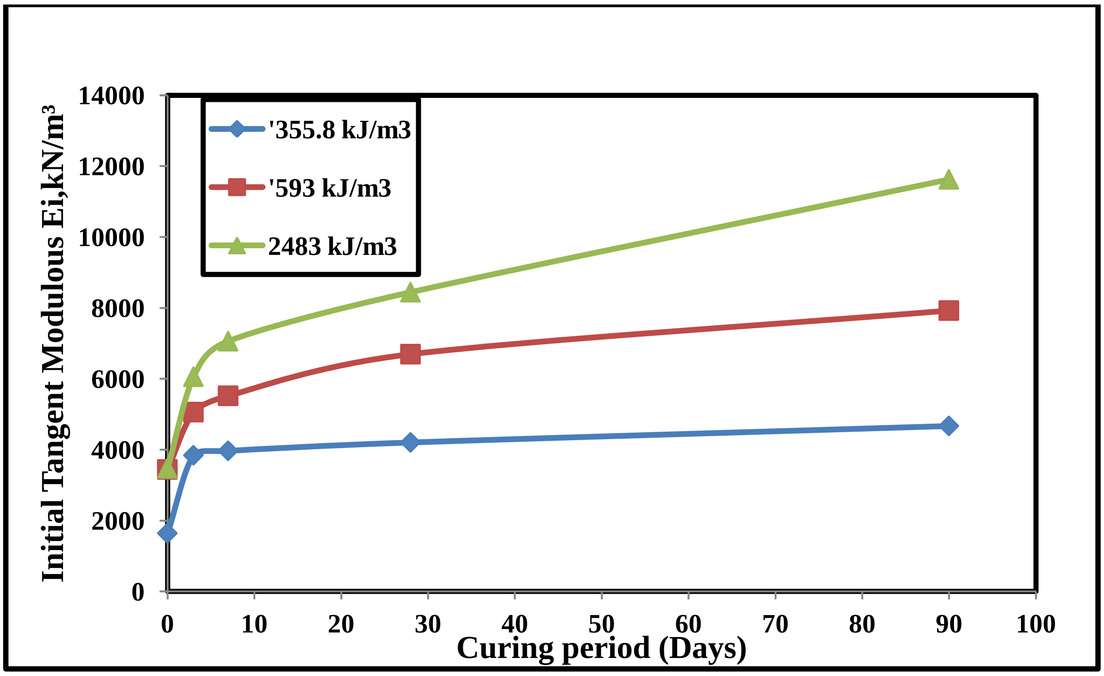

Figure 4.13: Variation of Initial tangent modulus with Curing period at different compaction energy

4.3.3. Determination of Shear Parameters

The shear parameters of the compacted fly ash specimens were determined for specimens compacted to different dry densities and moisture contents. Typical shear stress and normal stress relationship plots of compacted fly ash at different compaction energy are presented in Fig. 4.14.It is observed that the unit cohesion and the angle of internal friction vary from 10.7 to 13.4kPa and 24.84 to 27.34 degree with the change in compaction energy from 118.6 kJ/m^3 to 3483kJ/m^3. Singh and Panda [13] performed shear strength tests on freshly compacted fly ash specimens at various water contents and concluded that most of the shear strength is due to internal friction. The shear parameter of fly ash is a function of source of coal, degree of pulverization design and firing temperature of boiler units and degree of flocculation of particles in ash pond.

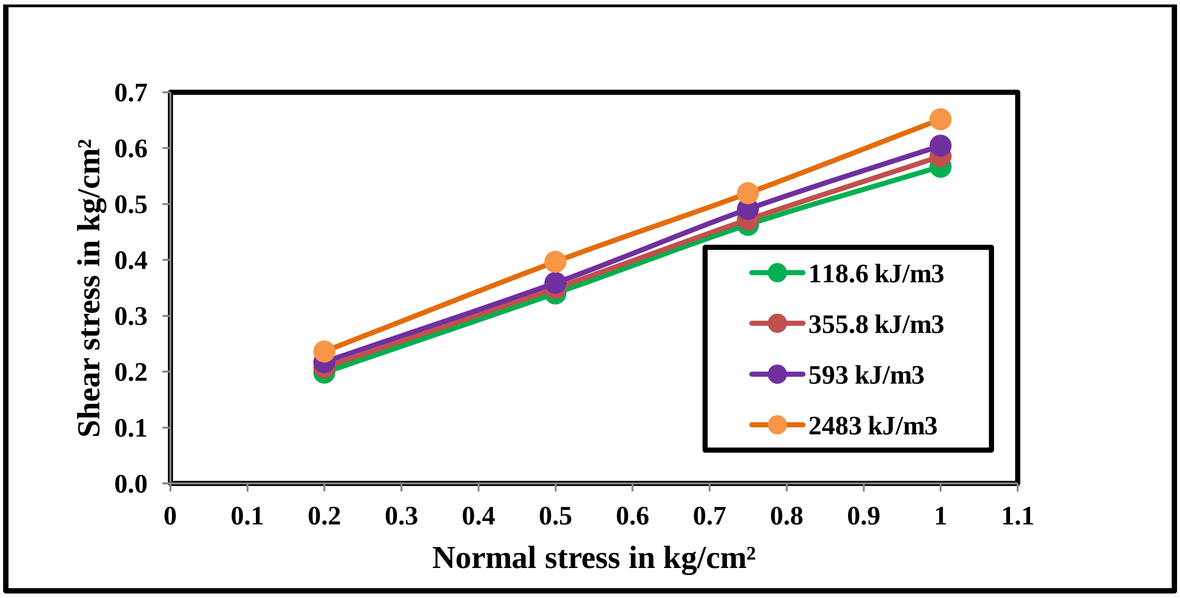

Figure 4.14: Normal stress Vs shear stress plot for compacted fly ash at different compaction energy

With increase in compaction energy results in more close packing of the particle. Due to closer arrangement the shear strength increases, so co-efficient of angle of friction increases. The variation of angle of internal friction with the compaction energy is shown in figure 4.15.

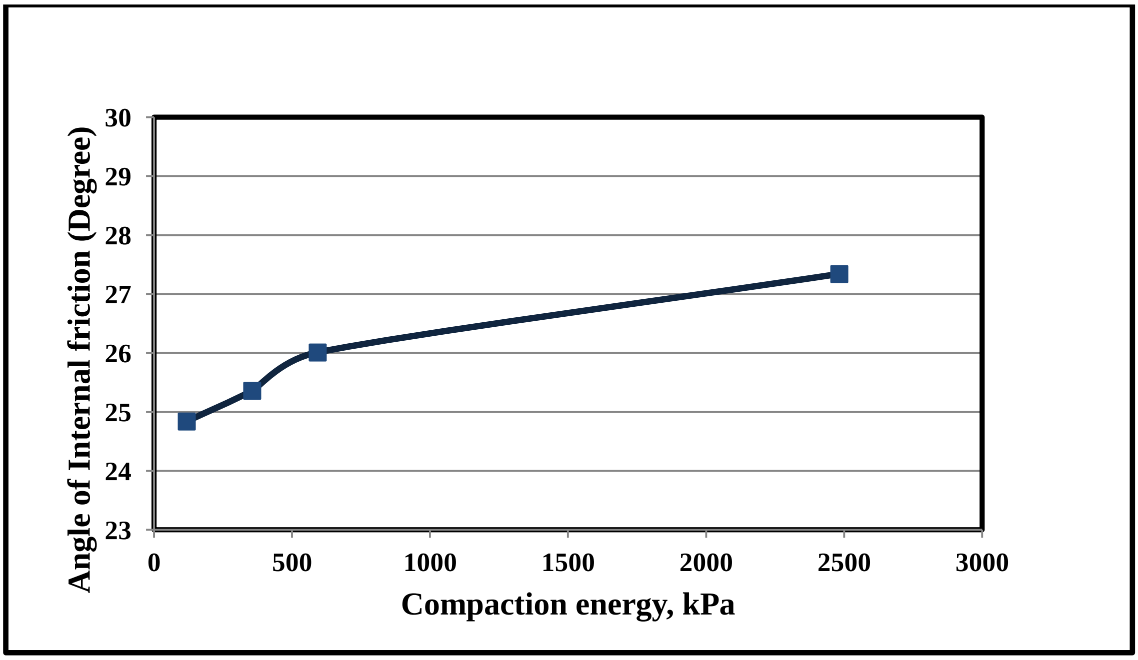

Figure 4.15: Variation of angle of internal friction with compaction energy for specimens compacted at different compaction energy

There is a negligible increase in cohesion component with increase in compaction energy. Increase in apparent cohesion basically due to surface tension. The graph showing the variation of unit cohesion with compaction energy is shown in figure 4.16.

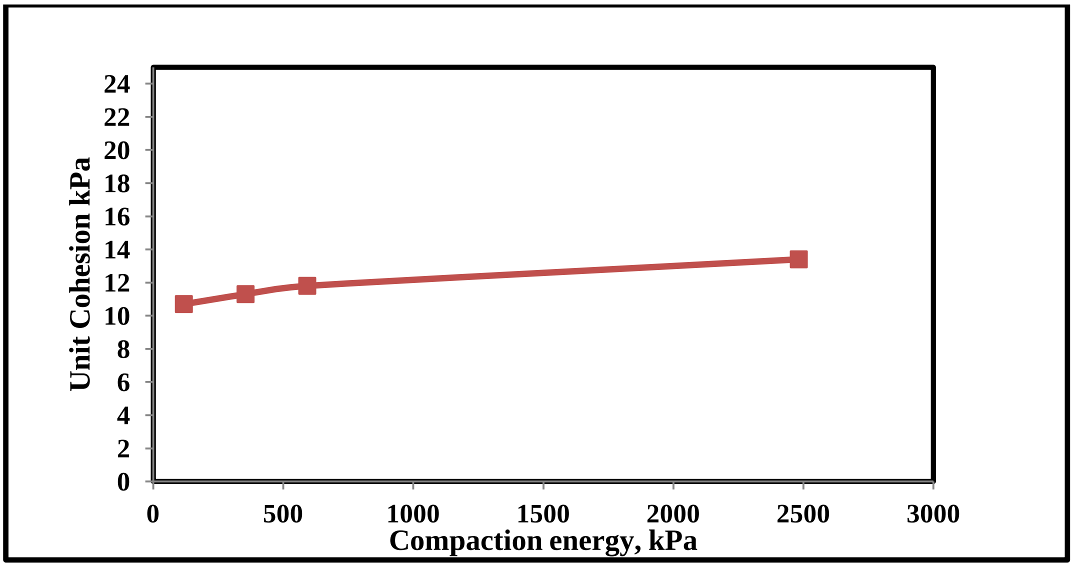

Figure 4.16: Variation of unit cohesion with compaction energy for specimens compacted at different compaction energy

4.3.4. CBR Value

CBR-value is used as an index of soil strength and bearing capacity. This value is broadly used and applied in design of the base and the sub-base material for pavement. CBR-test was conducted to characterize the strength and the bearing capacity of the fly ash. Toth et al. [11] reported the CBR values of coal ashes to vary between 6.8 and 13.5% for soaked condition, and 10.8 and 15.4% for unsoaked condition. Pond and bottom ashes show substantially higher CBR values. The typical CBR value of Badarpur coal ashes tested under soaked and unsoaked conditions reported by Pandian (2004)[15].The results under unsoaked conditions show higher CBR values ranging between 8.4 and 20.6%. This is mainly because fly ash, a fine-grained material, when placed at 95% of Proctor maximum dry density and corresponding water content, exhibits capillary forces, in addition to friction resisting the penetration of the plunger and thus high values of CBR are obtained. On the contrary, when the same fly ash samples are soaked for 24 h maintaining the same placement conditions, they exhibited very low values of CBR. This can be attributed to the destruction of capillary forces under soaked conditions [15]. The load- penetration curves for fly ash compacted at different compaction energy are shown in figure below.

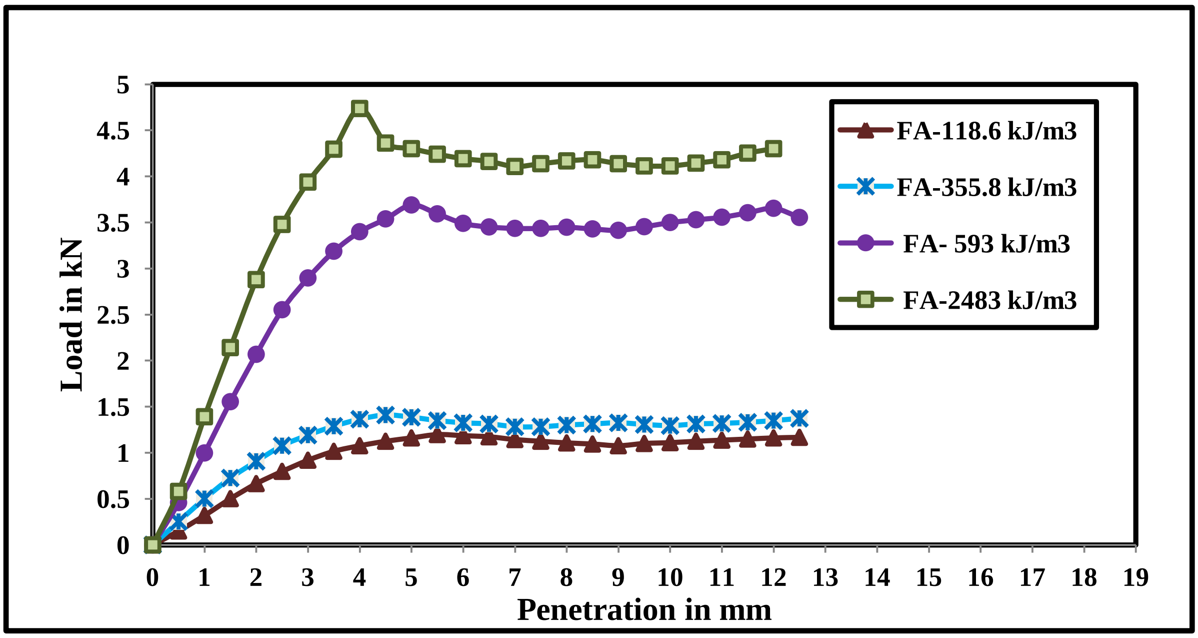

Figure 4.17: Load Vs Penetration curve of fly ash compacted at different compaction energy under unsoaked condition

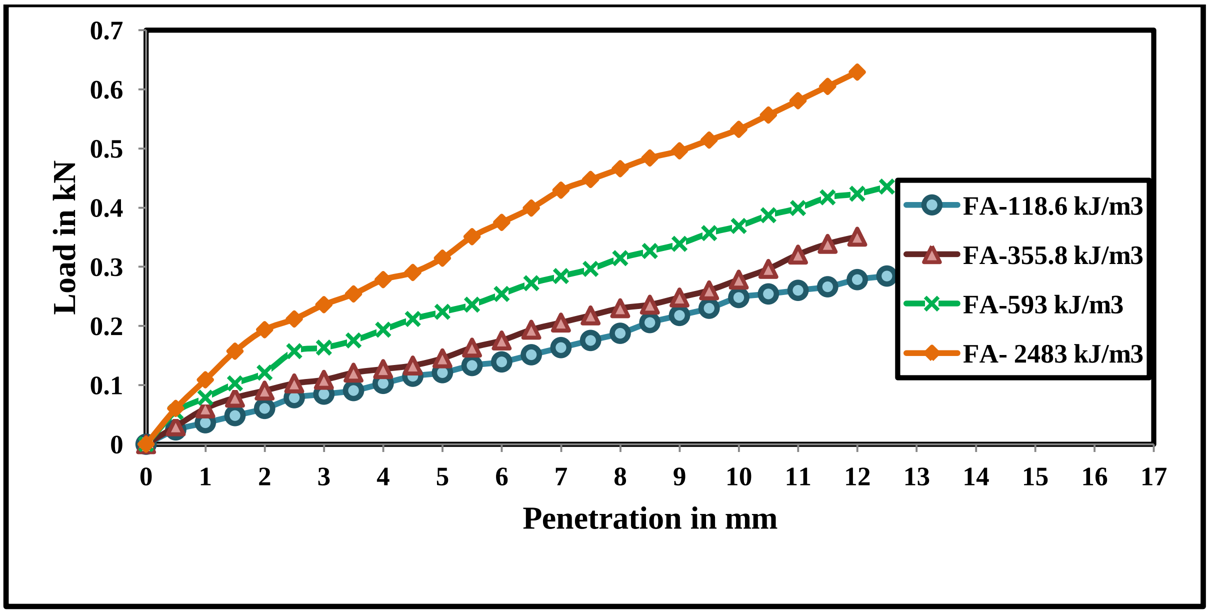

Figure 4.18: Load Vs Penetration curve of fly ash compacted at different compaction energy under soaked condition

The highest unsoaked and soaked CBR value found to be 25.39% and 1.546% at compaction energy of 2483 kJ/m3.The soaked CBR value is very less as compared to unsoaked CBR .this is due to destruction of capillary force under soaked condition.

The variation of Initial tangent modulus with compaction energy is shown in Figure 4.19.

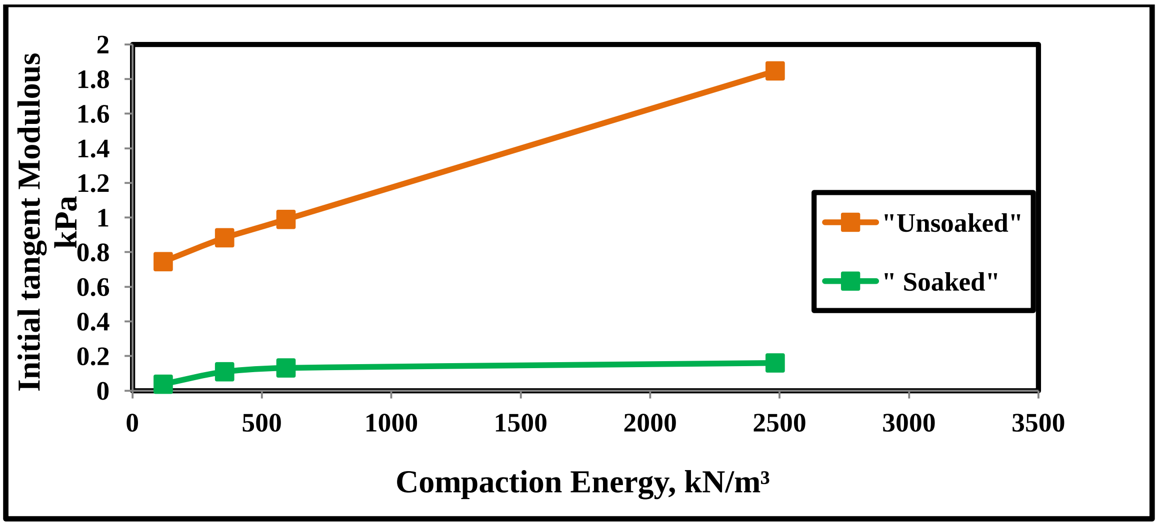

Figure 4.19: Variation of Initial tangent modulus in unsoaked and soaked condition with different compaction energy

From the graph it is clear that a linear relationship between Initial tangent modulus and compaction energy. There is a sharp increase in the Initial tangent modulus in case of unsoaked CBR test indicates that stiffness increases with increase in compaction energy.

4.3.5. Permeability

The coefficient of permeability of ash depends upon the grain size, degree of compaction and pozzolanic activity. The variation of co-efficient of permeability (k) with compactive energy is shown in Figure 4.20.Value of k decreases with increase in compaction energy.

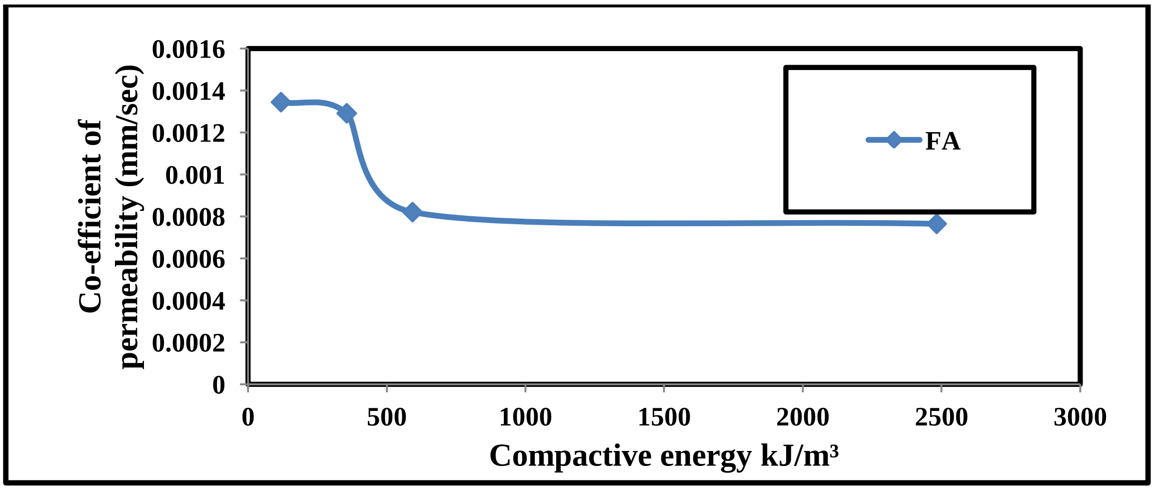

Figure 4.20: Variation of co-efficient of permeability with compactive energy

CHAPTER 5

(GEOTECHNICAL PROPERTY OF LIME TREATED FLY ASH)

5.1. INTRODUCTION

The strength of fly ash generally improves with time due to pozzolanic reactions. Reactive silica and free lime contents are necessary for pozzolanic reactions to take place .However class-F Fly ash contain very low percentage of free lime. When stabilized with lime and cured at high temperature strength of fly ash can significantly improve. The main aim of this project is to analyze the improvement in the geotechnical properties like compaction Characteristics, shear parameters and compressive strength etc. The variation in the properties of lime treated fly ash and that of raw fly ash are discussed in this section.

5.2. INDEX PROPERTIES

5.2.1. Specific Gravity

The specific gravity test was done as per Indian standard IS: 2720(Part III)-1980 with kerosene and de airing by heat on sand bath. With increase in lime content of 1% to 10% specific gravity increases from 2.56 to 2.66.

5.3. ENGINEERING PROPERTIES

5.3.1. Compaction Characteristics

5.3.1.1. Effect of compaction energy

The compaction characteristics of lime treated fly ash with different compaction energies have been studied by varying the compaction energies as118.6, 355.8, 593, and 2483 kJ/m^3 of compacted volume. The OMC and MDD of fly ash samples corresponding to these compactive efforts have been evaluated and presented in Table 3.6. Relationship between dry density and moisture content of fly ash at different compaction energies have been shown in Fig 5.1,5.2, 5.3 and 5.4. It is seen that as the compactive energy increases the MDD increases and the water required to achieve this density is reduced. A continuous increase in the value of MDD is observed with the compactive energy (Fig.5.5). Plot between OMC and compactive energy (Fig.5.6) shows that initially the OMC decreases rapidly with compactive effort and then the rate of decrease is not that prominent .The maximum value of MDD obtained for Fly ash with 10% lime is found to 1.365kJ/m3 with corresponding OMC of 19.5% at compaction energy of 2483kJ/m3 .

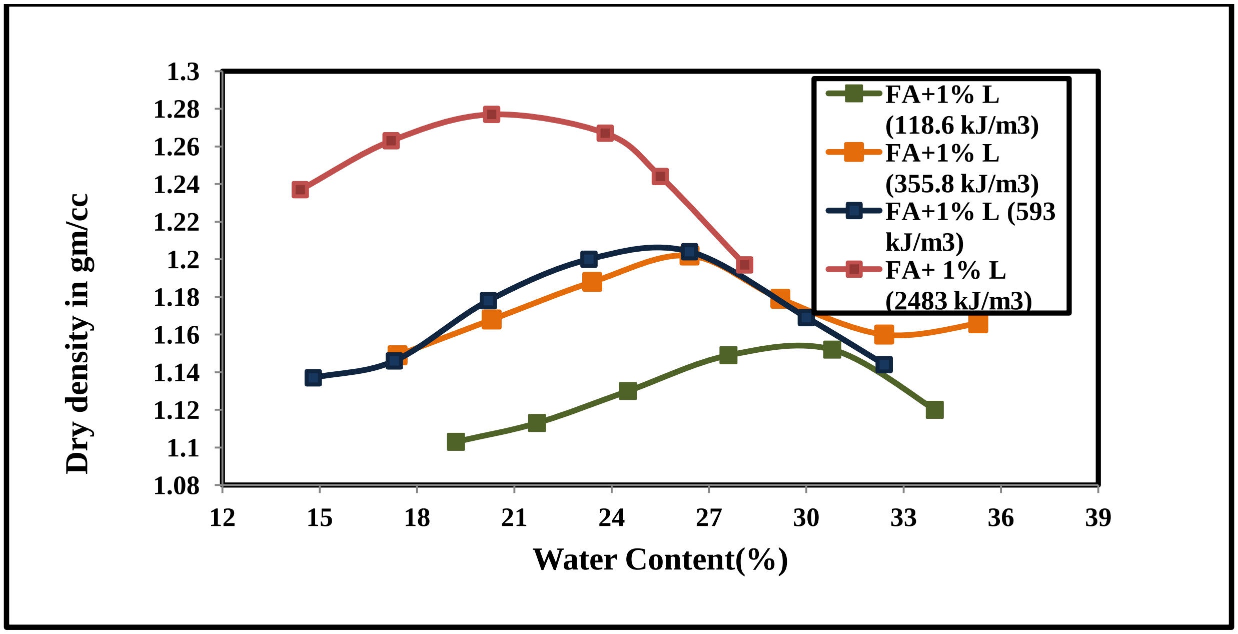

Figure 5.1: Compaction curve of Fly ash+1% Lime at different compaction energy

With increase in compaction energy from118.6 kJ/m^3 to 2483 kJ/m^3 dry density increases from 1.153 kJ/m^3 to 1.278 kJ/m^3 and correspondingly moisture content decreases from 30% to 23.1 %. Compaction curve of Fly ash+2% Lime at different compaction energy is shown in figure 5.2.

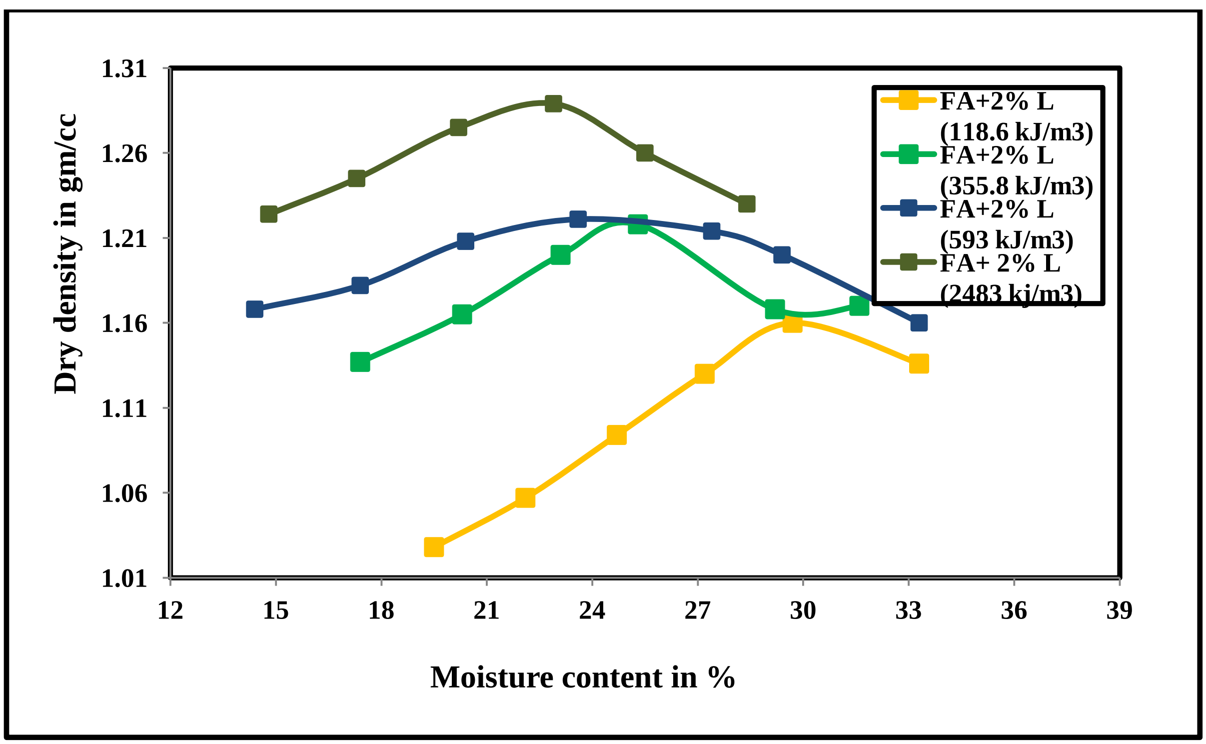

Figure 5.2: Compaction curve of Fly ash+2% Lime at different compaction energy

With increase in compaction energy from118.6 kJ/m^3 to 2483 kJ/m^3 dry density increases from 1.16kJ/m^3 to 1.29 kJ/m^3 and correspondingly moisture content decreases from 29.4% to 22.5 %. Compaction curve of Fly ash+5% Lime at different compaction energy is shown in figure 5.3.

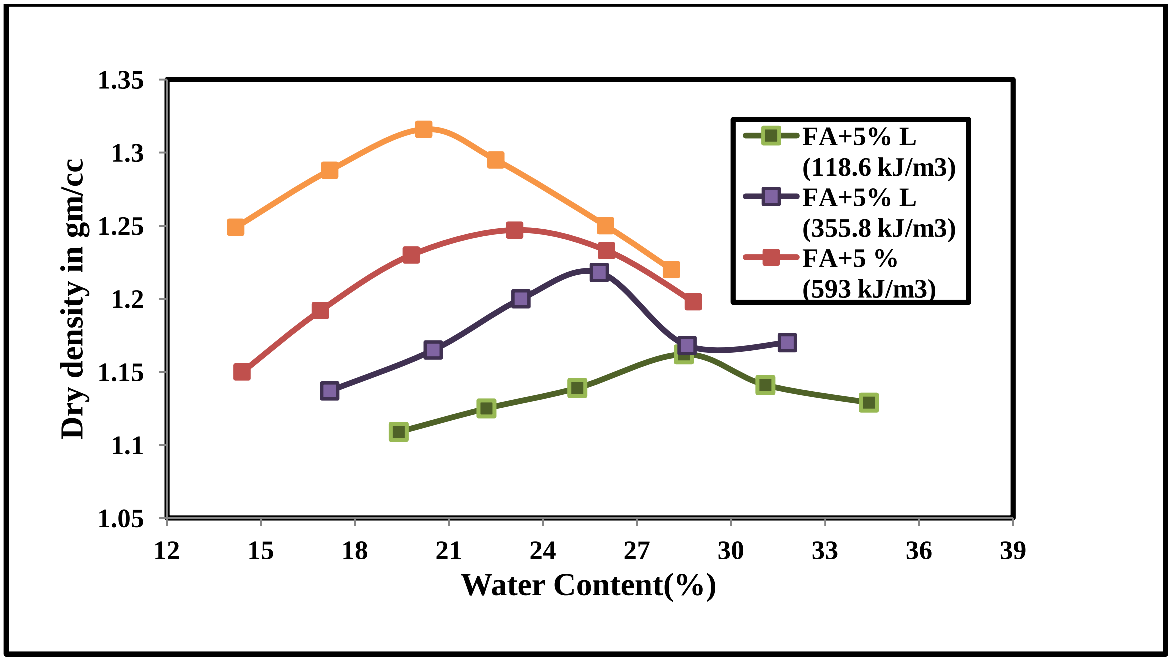

Figure 5.3: Compaction curve of Fly ash+5% Lime at different compaction energy

With increase in lime percentage dry density increases and this trend is more effective with increase in compaction energy. At relatively higher compaction energy, MDD increases with addition of lime result in increase in dry density.

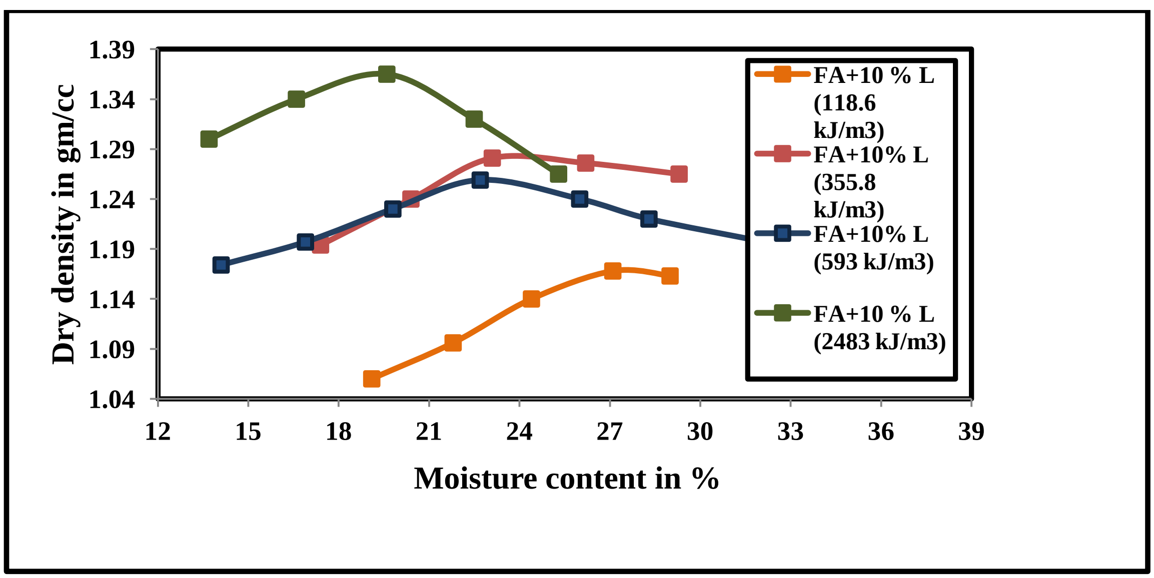

Figure 5.4: Compaction curve of Fly ash+10% Lime at different compaction energy

The maximum dry density of fly ash treated with 10% Lime increases from 1.168 gm/cc to 1.365 gm/cc with increase in compaction energy from118.6 kJ/m^3 to 2483 kJ/m^{3}and corresponding OMC decrease from 27.6% to 19.5%.

The variation of MDD and OMC with different compaction energy is shown in Figure 5.5 and 5.6.From this it clear that with increase in compaction energy from118.6 kJ/m^3 to 2483 kJ/m^3 MDD increases. This due to closer packing of fly ash particle under the increasing compactive effort.

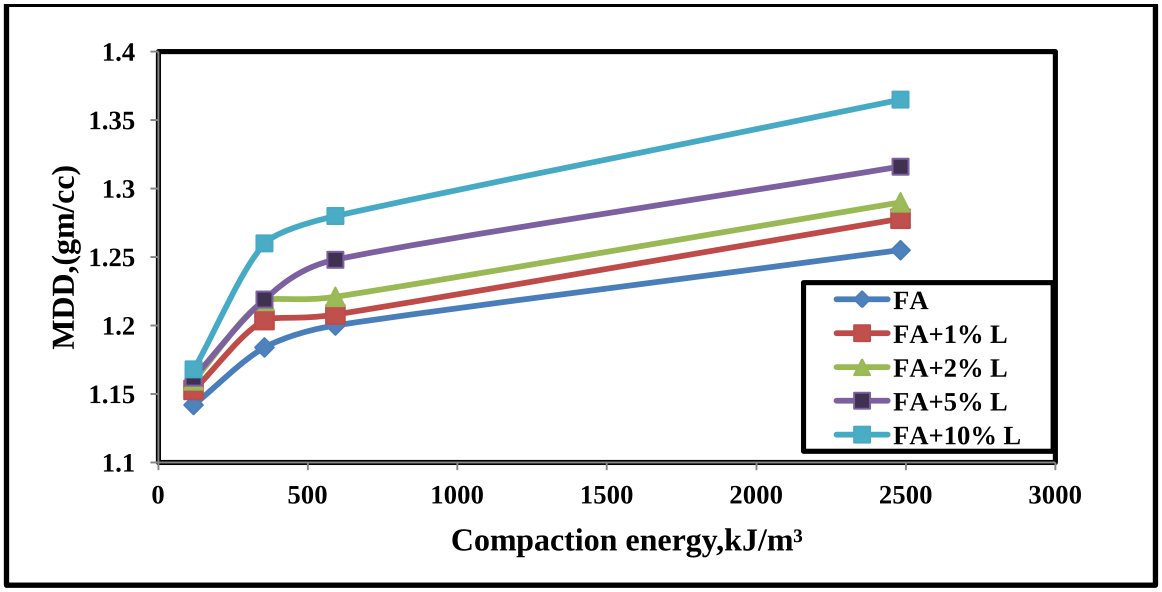

Figure 5.5: Variation of MDD with compaction energy at different lime content

The variation of OMC with compaction energy shown in figure 5.6.As the Compaction energy increases OMC decreases.

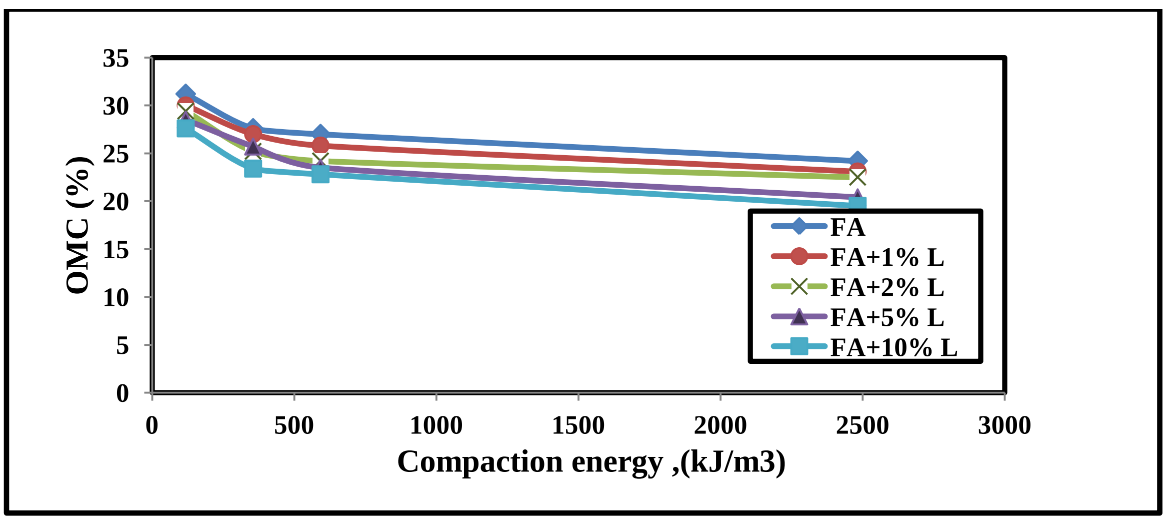

Figure 5.6: Variation of OMC with compaction energy at different lime content

5.3.1.2 Effect of Lime

With increase in lime content the MDD increases and OMC decreases. However increase in MDD and decrease in OMC significantly low up to addition up to 2% of lime .With further increase in lime there are a remarkable increase in MDD and decrease in OMC. Maximum MDD of 1.365gm/cc achieves at a lime content of 10%.The variation of MDD and OMC with lime content shown in Figure 5.7.

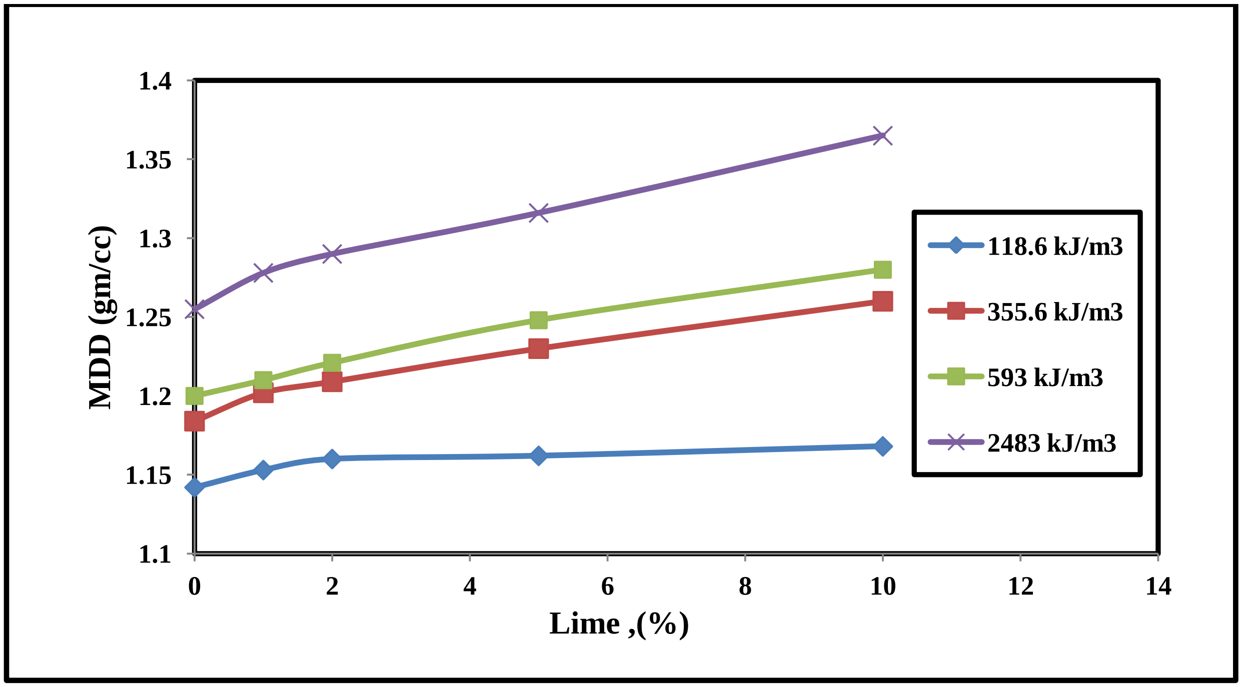

Figure 5.7: Variation of MDD with Lime at different compaction energy

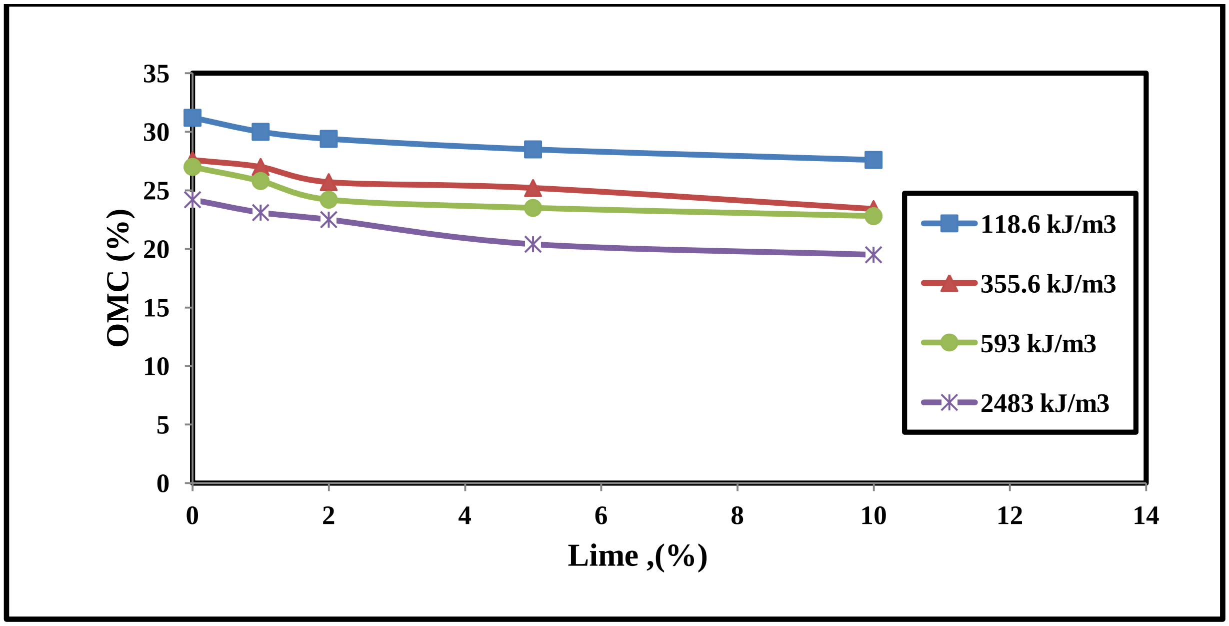

Figure 5.8: Variation of OMC with Lime at different compaction energy

5.3.2. Determination of Unconfined compressive strength

5.3.2.1. Effect of compaction energy

Sherwood and Ryley reported that the fraction of lime, present as free lime in the form of calcium oxide or calcium hydroxide, controls self-hardening characteristics of fly ashes. Digioia and Nuzzo indicated that age hardening can be best correlated with the amount of free lime present in the fly ash [10]. Singh studied the unconfined compressive strength of fly ashes as a function of free lime present in them [13].Unconfined compressive strength tests were carried out on Lime treated fly ash specimens compacted to their corresponding MDD at OMC with compactive effort varying as 355.8, 593 and2483kJ/m3. These samples are subjected to curing period of 3, 7, 28, 90 days in a humidity chamber at an average temperature of 33º C. Stress-strain relationships of compacted lime treated fly ash were presented in Fig 5.17, 5.18, 5.19 and 5.20. Form these plots it is observed that the failure stress as well as initial stiffness of samples, compacted with greater compaction energy, are higher than the samples compacted with lower compaction energy. With increase in compaction energy a sharp peak in stress- strain curve indicate the brittle failure of the lime treated fly ash samples. Variation of UCS value with the compaction energy Immediate and after 3, 7, 28 and 90 days of curing shown in Figure 5.9, 5.10, 5.11, 5.12 and 5.13.

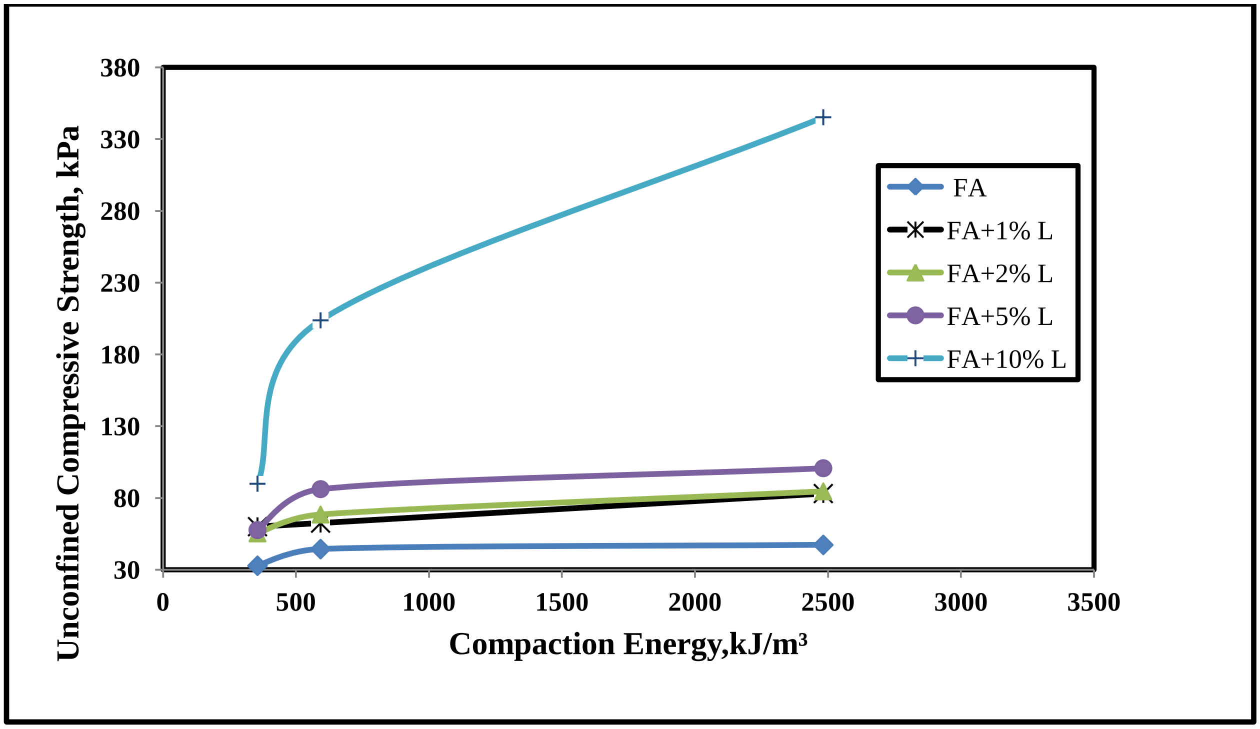

Figure 5.9: Variation of UCS value of immediate compacted lime treated fly ash with different compaction energy

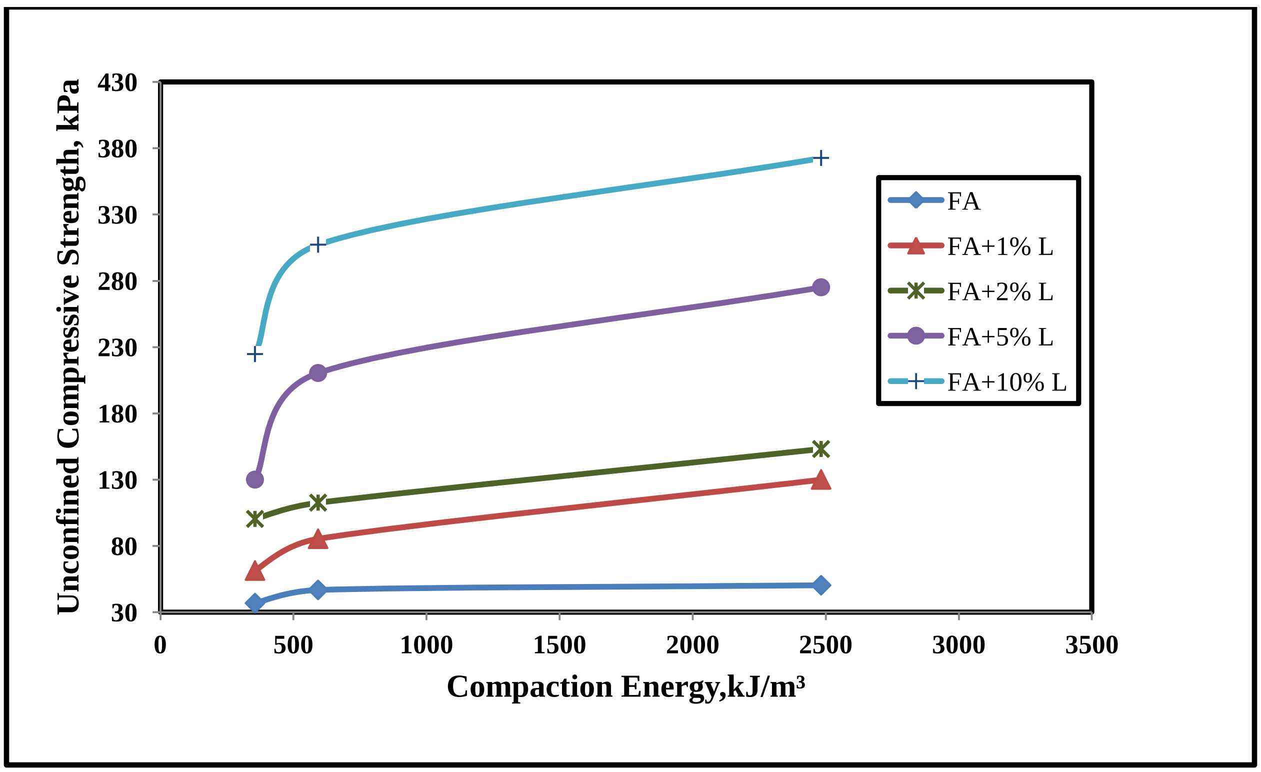

Figure 5.10: Variation of UCS value of lime treated fly ash with different compaction energy after 3 days of curing

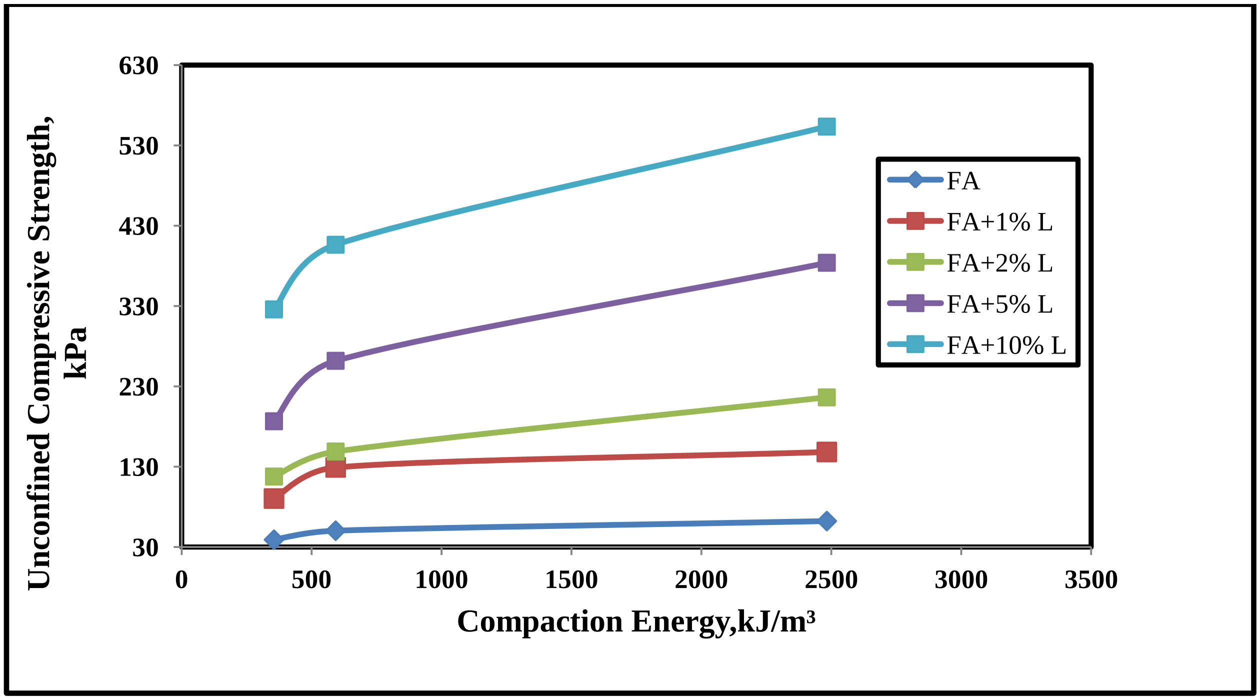

Figure 5.11: Variation of UCS value of lime treated fly ash with different compaction energy after 7 days of curing

With increase in compaction energy followed by curing period shows a significant increase in strength due to closer packing of particles .Besides increased duration of curing, leading to prolonged pozzolanic reaction producing cementious gel that result in increase in strength.

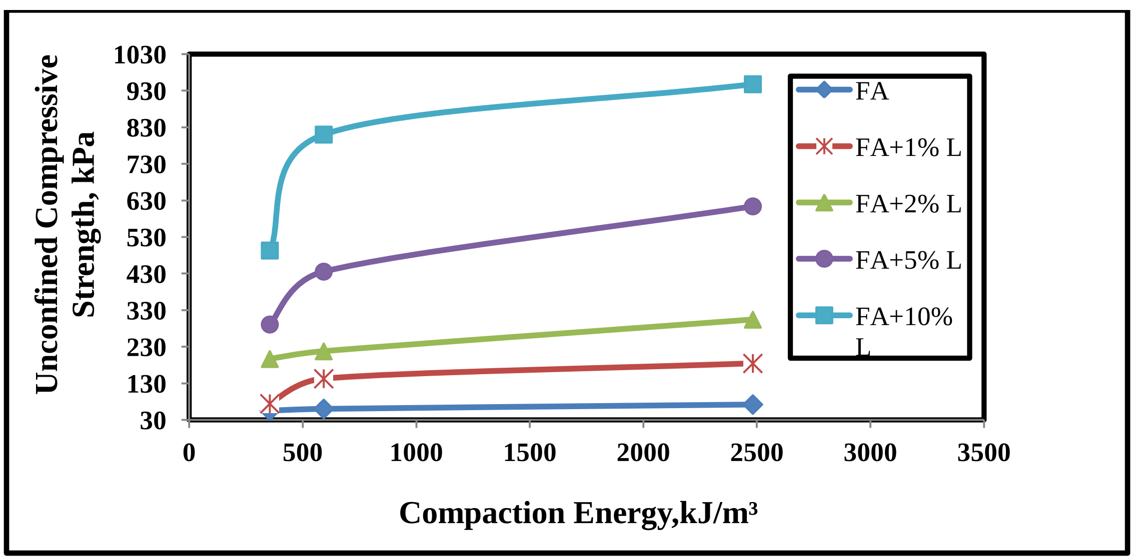

Figure 5.12: Variation of UCS value of lime treated fly ash with different compaction energy after 28 days of curing

Variation of UCS value of lime treated fly ash with different compaction energy after 90 days of curing shown in figure 5.13.

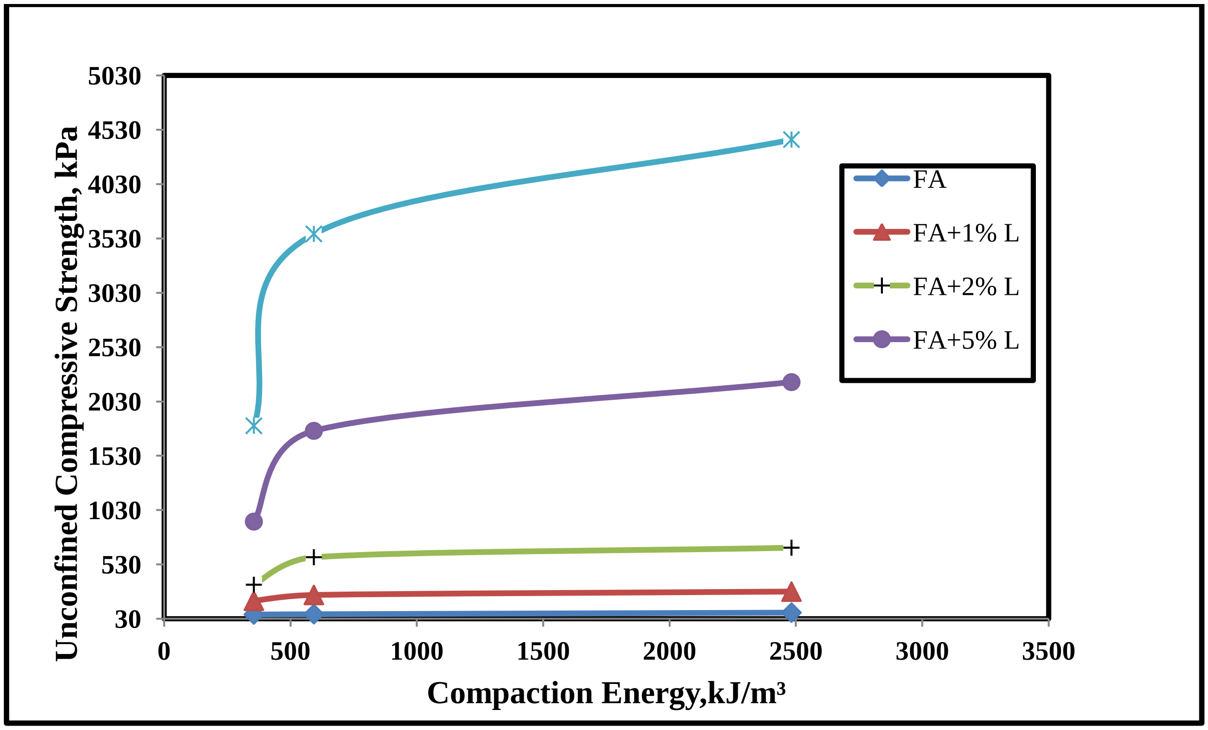

Figure 5.13: Variation of UCS value of lime treated fly ash with different compaction energy after 90 days of curing

5.3.2.2. Effect of curing period

The unconfined compressive strength increases with curing period. According to Das and Yudhbir(2004) stress-strain behavior during uncompression test on samples cured for different duration for Neyveli fly ash shows like that of "cemented soil"[13]. Yudhbir and Honjo(1991) have classified Fly ash into three categories based on the self-hardening value. Class I-The self-hardening value increases rapidly for 28 days and reaches value close to 20 N/mm^2.class II self-hardening value of 1-3 N/mm^2 with 12-16 weeks with moderate increase in strength, and class III very slow rate of increase in strength varying from 0.1 to 0.4 N/mm^2. With increase in curing period from 3 to 90 days the effect of lime is more pronounced. Increase in curing period enhances the lime fly ash reaction result in increase in strength due to formation of cementitious gel that bind particle together. Variation of UCS with curing period at compacted energy of 355.8 kJ/m^3 is shown in figure 5.14.

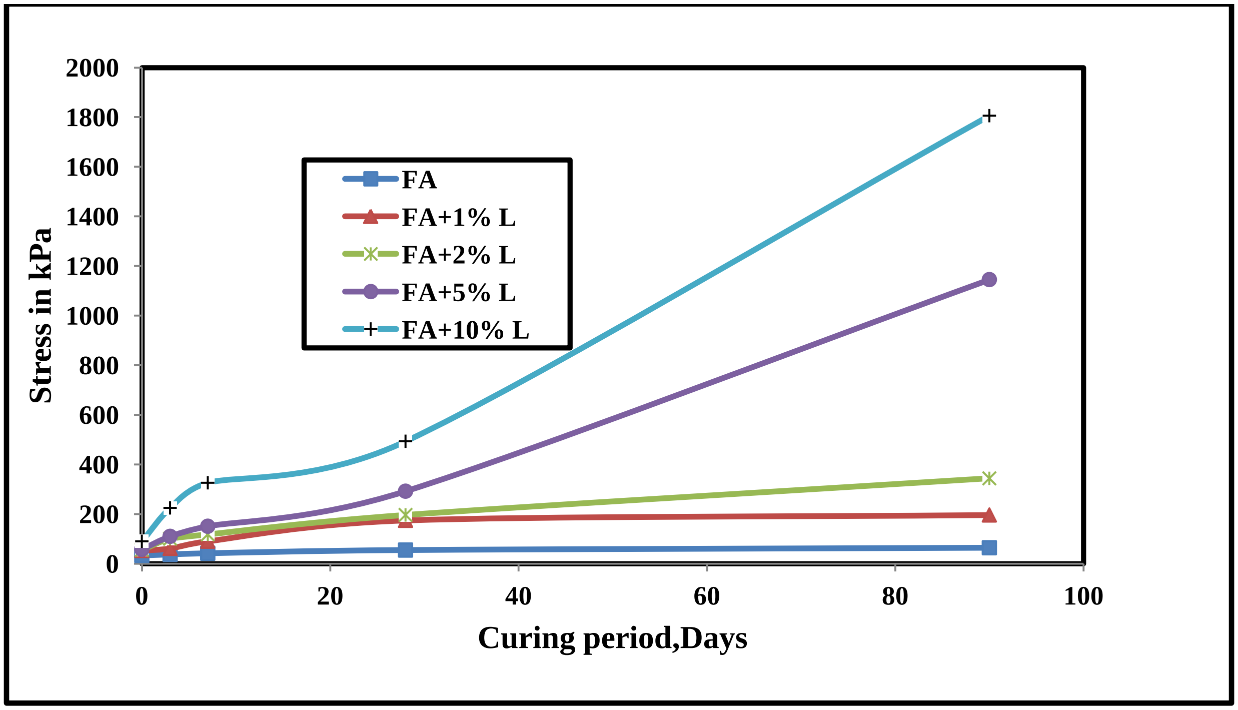

Figure 5.14: Variation of UCS with curing period at compacted energy of 355.8 kJ/m^3

Variation of UCS with curing period at compacted energy of 593 kJ/m^3 is shown in figure 5.15.

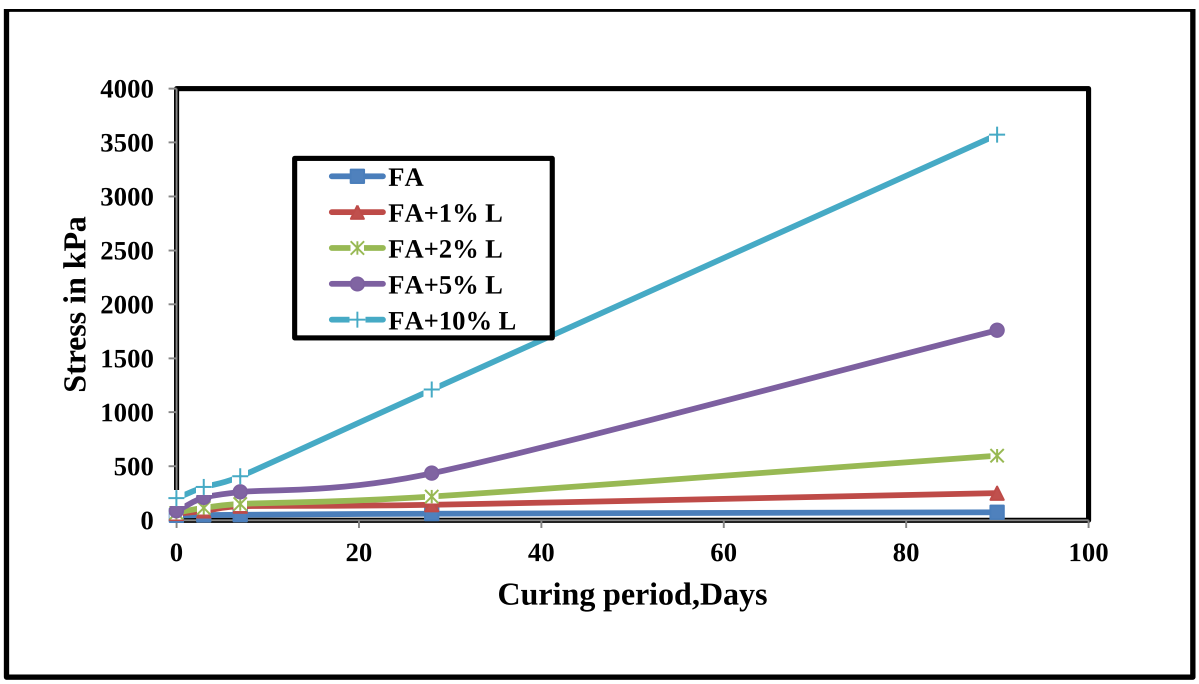

Figure 5.15: Variation of UCS with curing period at compacted energy of 593 kJ/m^3

The variation of UCS with curing period at compaction energy of 2483 kJ/m^3 is shown in figure 5.16.

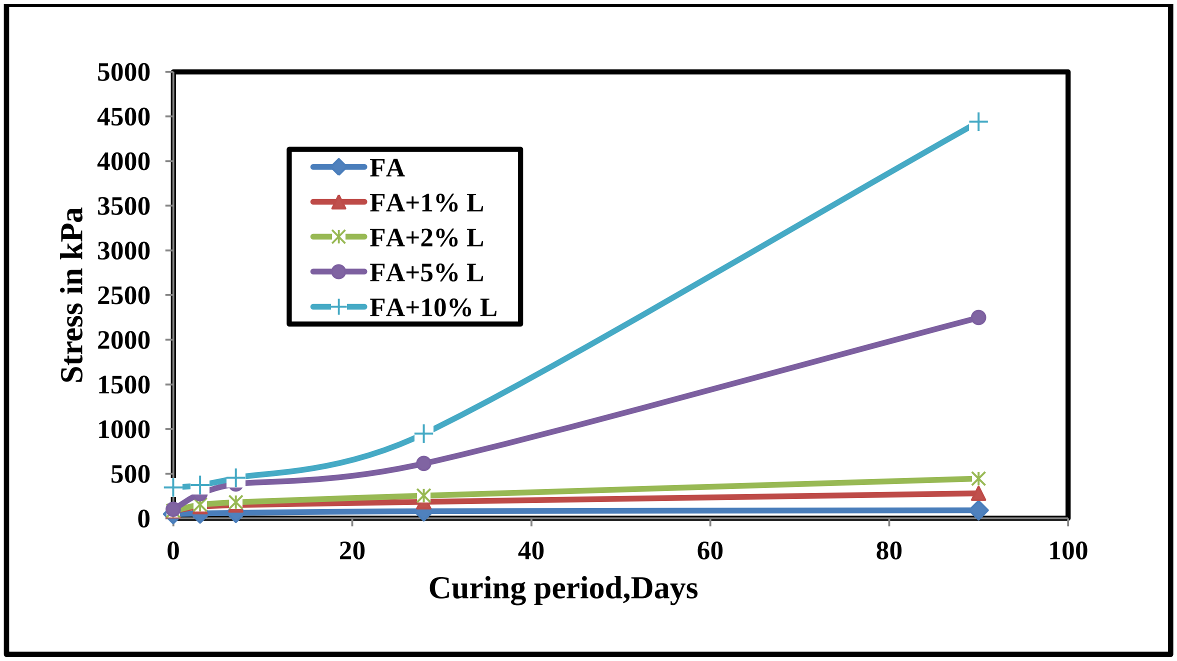

Figure 5.16: Variation of UCS with curing period at compacted energy of 2483 kJ/m^3

The stress-strain curve of lime treated fly ash at different compaction energy shown in Figure 5.17. From this graph it is clear that for a constant compaction energy the stress increases with increase in curing period marked by a higher peak in stress-strain curve.

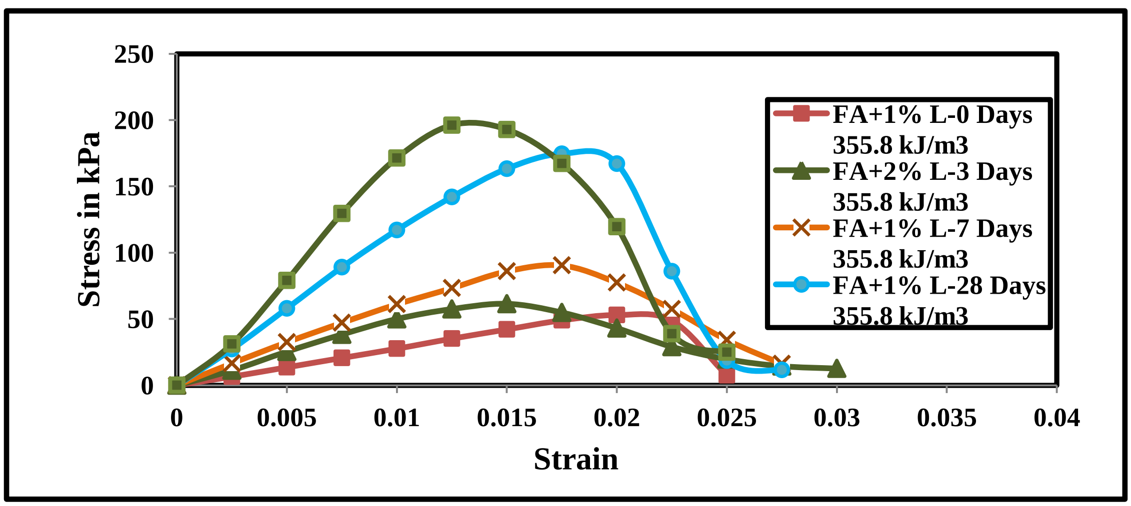

Figure 5.17: Stress-strain curve of Fly ash +1% L at compaction energy of 355.8 kJ/m^3 after different curing period

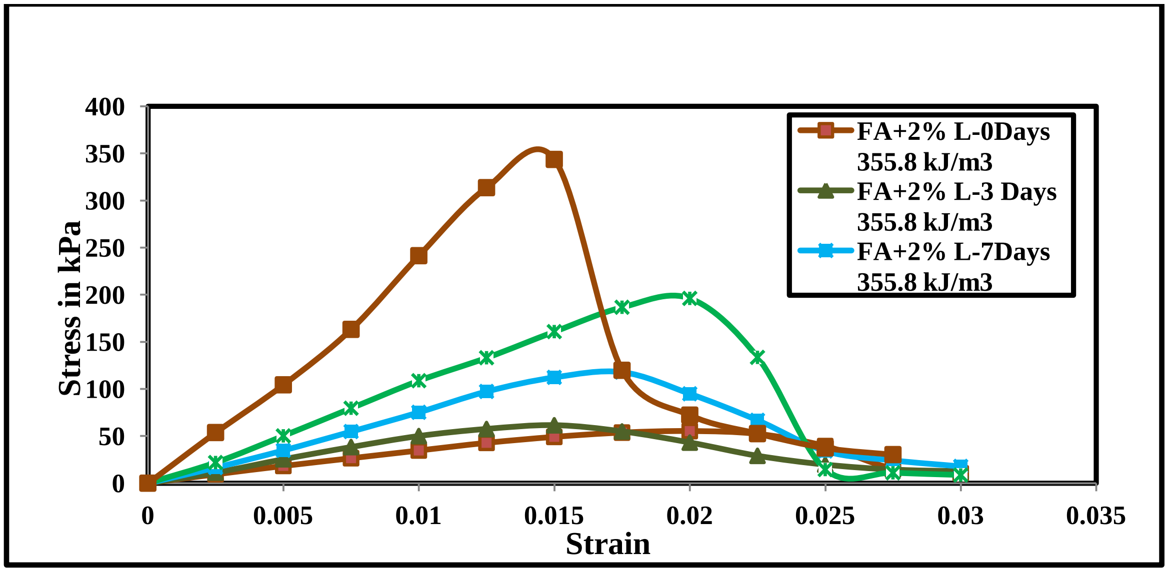

Figure 5.18: Stress-strain curve of Fly ash +2% L at a compaction energy of 355.8 kJ/m^3 after different curing period

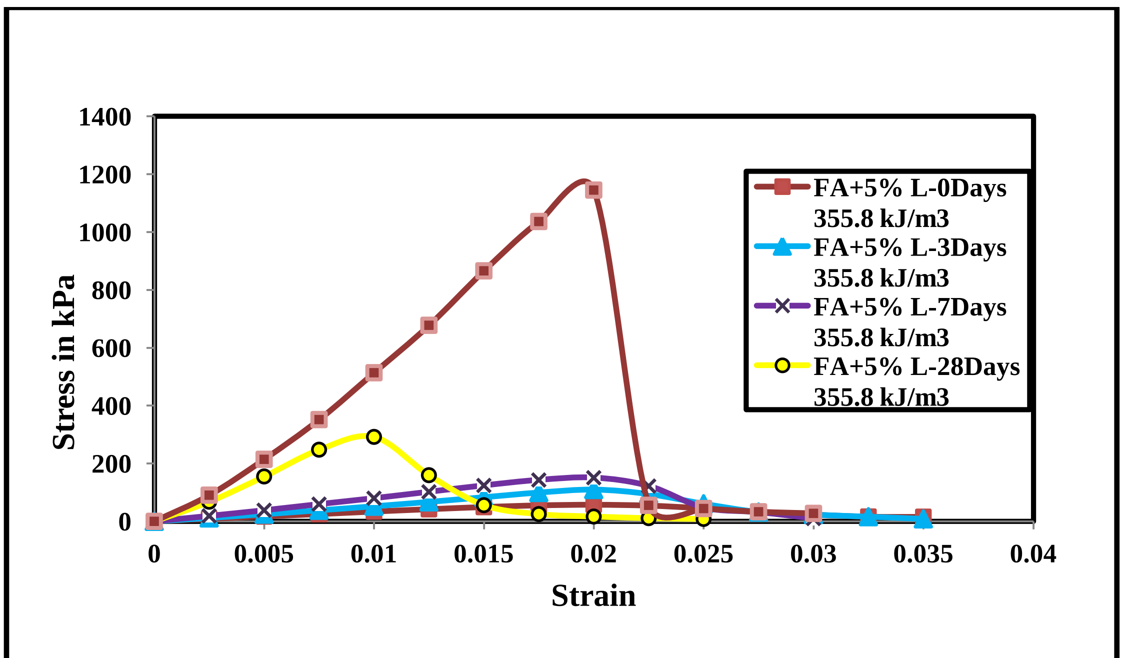

Figure 5.19: Stress-strain curve of Fly ash +5% L at a compaction energy of 355.8 kJ/m^3 after different curing period

When lime is small in quantity, that's about 1%, the strength improvement is practically negligible, even if cured for long. With increased lime content the pozzolanic reaction peaks up producing adequate amount of cementitious compounds leading to visible increase in strength. As the lime percentage increases this facilitates the pozzolanic reaction that form cementiceous gel that bind particle. This process is catalyst by increase in curing period .The UCS value of fly ash with 5% of lime reaches a value of 292.043 kPa which further increase to 493.279 kPa for sample with 10% of lime. The figure showing the variation of stress –strain of fly ash with10% lime at compaction energy of 355.8 kJ/m^3 is shown in figure 5.20.

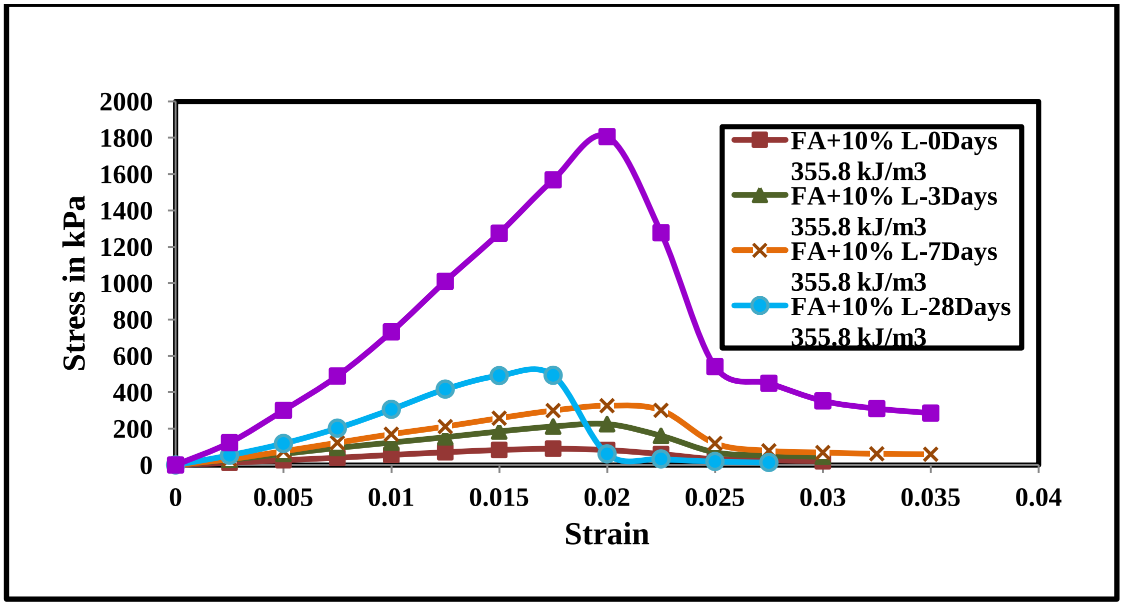

Figure 5.20: Stress-strain curve of Fly ash +10% L at a compaction energy of 355.8 kJ/m^3 after different curing period

With further increase in compaction energy from 355.8 kJ/m^3 to 2483 kJ/m^3 result in increase in strength which indicated by relatively more stiffness.

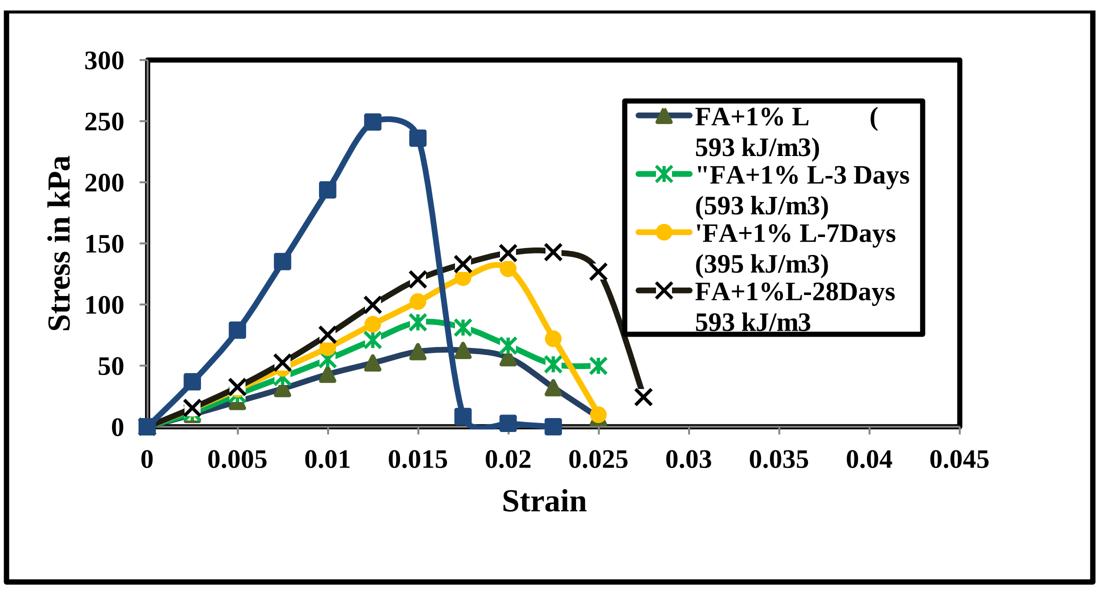

Figure 5.21: Stress-strain curve of FA+1 % L at a compactive energy of 593 kJ/m^3

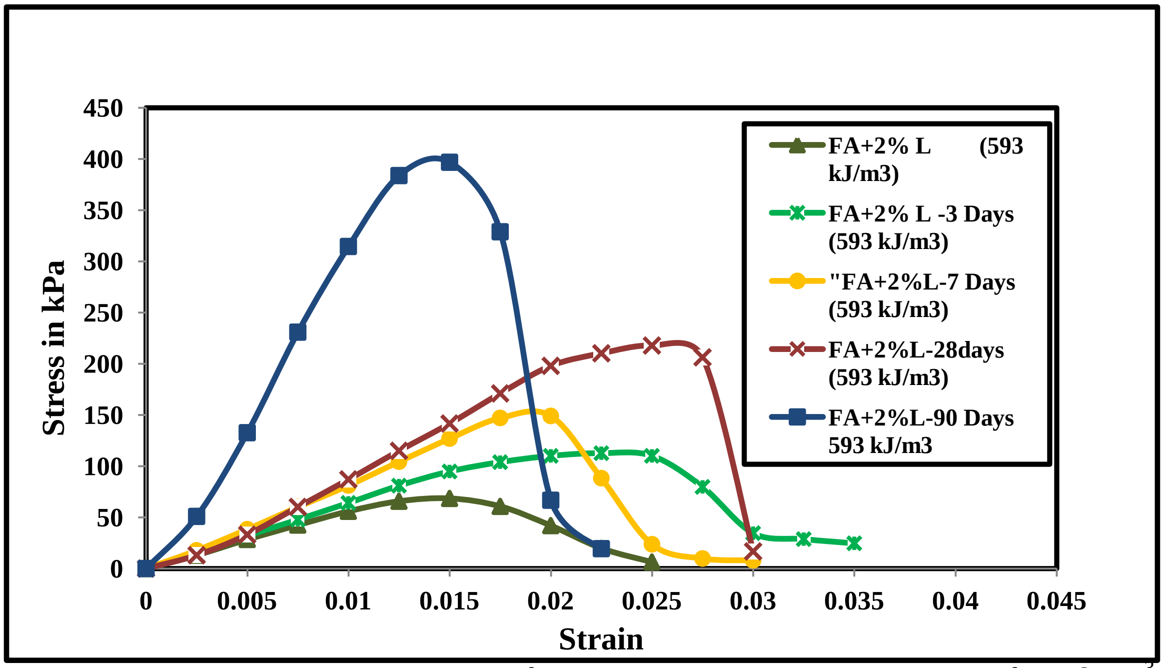

Figure 5.22: Stress-strain curve of FA+2 % L at a compactive energy of 593 kJ/m^3

UCS of untreated fly ash after 90 days of curing was found to be 72.642 kPa. With increase in lime percentage of 1% UCS value reaches to 249.29 kPa which further increased to 3572.07 kPa for fly ash stabilized with 2% of lime.

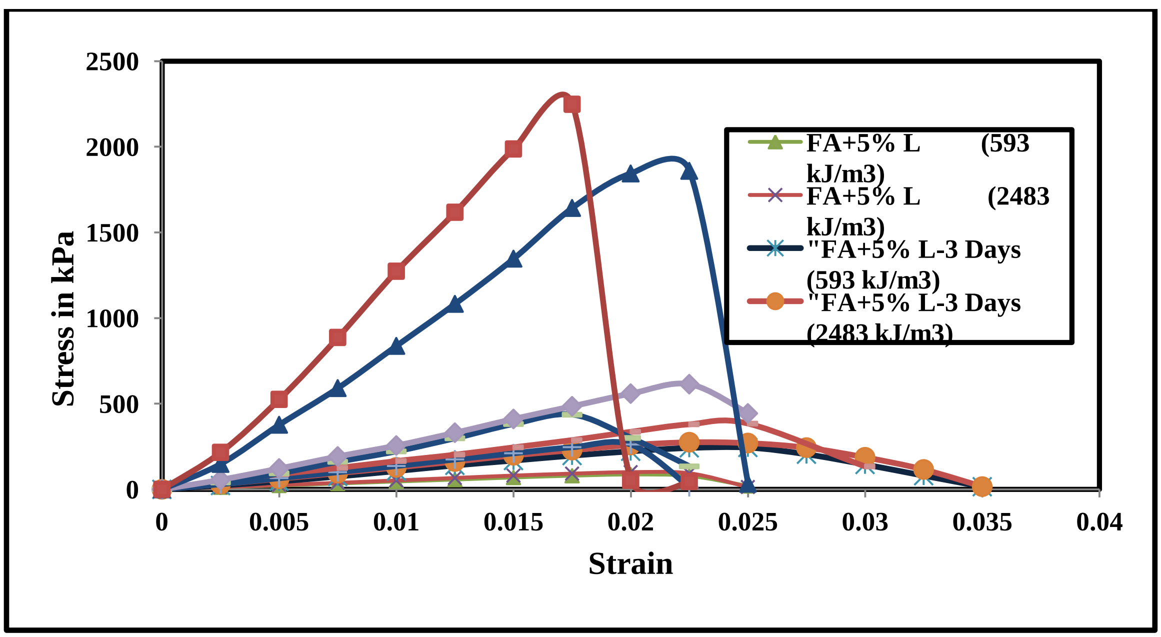

Figure 5.23: Stress-strain curve of FA+5 % L at a compactive energy of 593 kJ/m^3

As compactive energy increases more brittle failure result.UCS value for fly ash stabilized with 5% lime was found to be 1759.5 kPa after 90 days of curing, which is approximately 24 times the strength obtained for untreated fly ash.

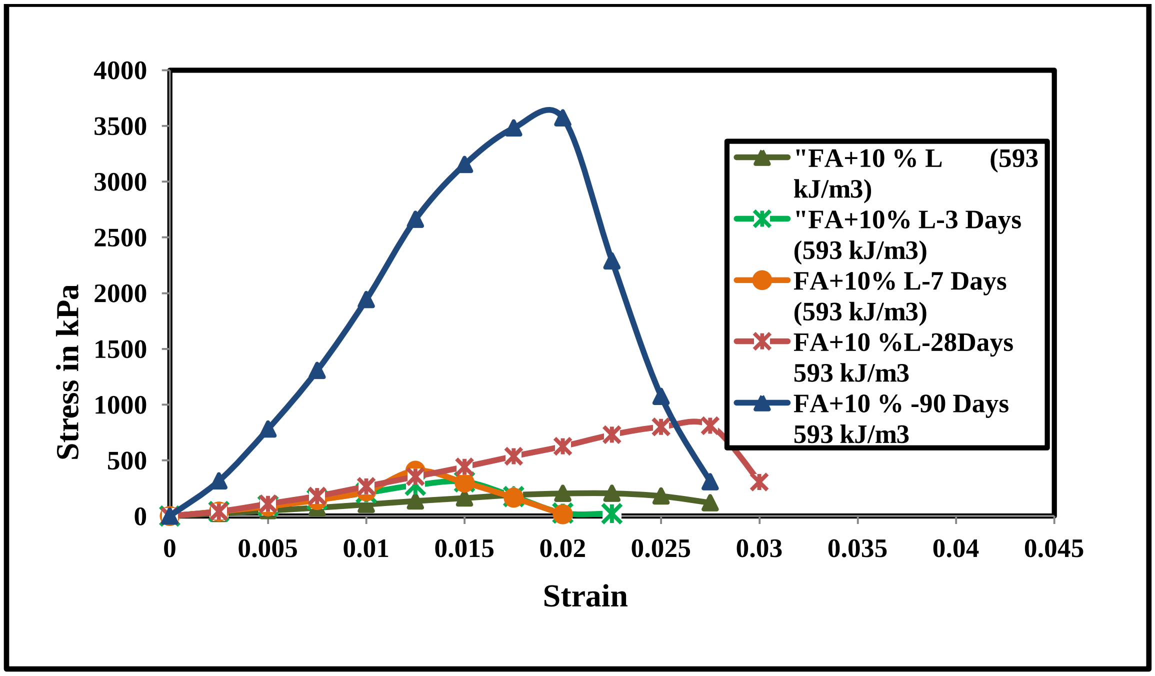

Figure 5.24: Stress-strain curve of FA+10% L at a compactive energy of 593 kJ/m^3

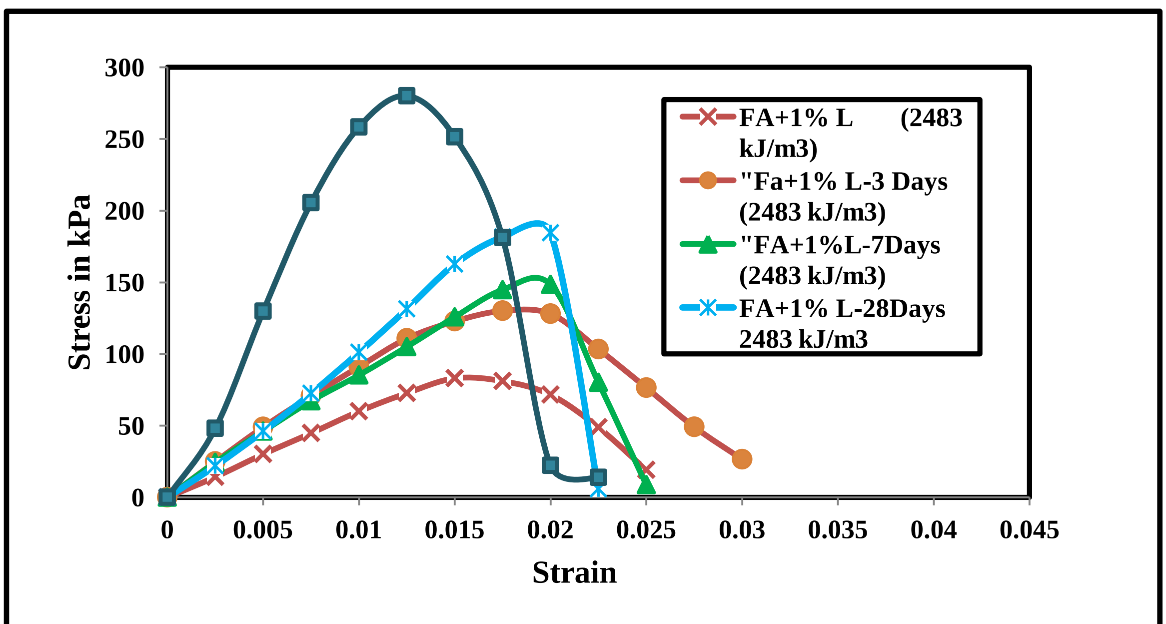

Figure 5.25: Stress-strain curve of FA+1 % L at a compactive energy of 2483 kJ/m^3

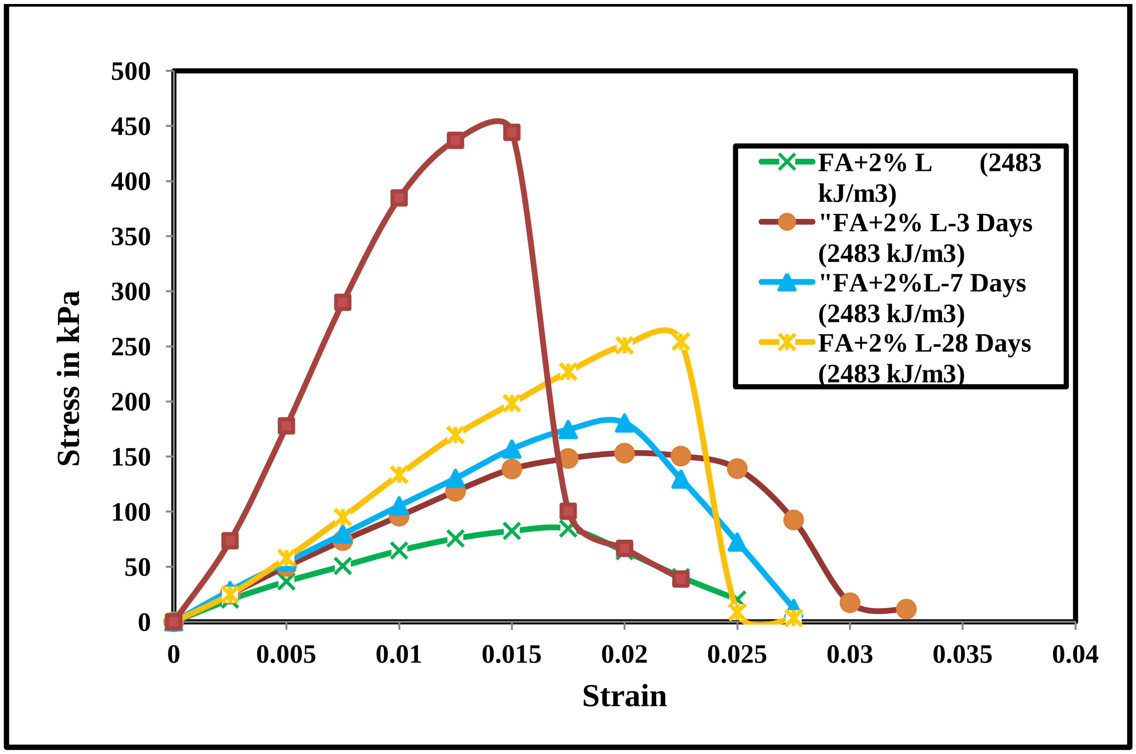

Figure 5.26: Stress-strain curve of FA+2% L at a compactive energy of 2483 kJ/m^3

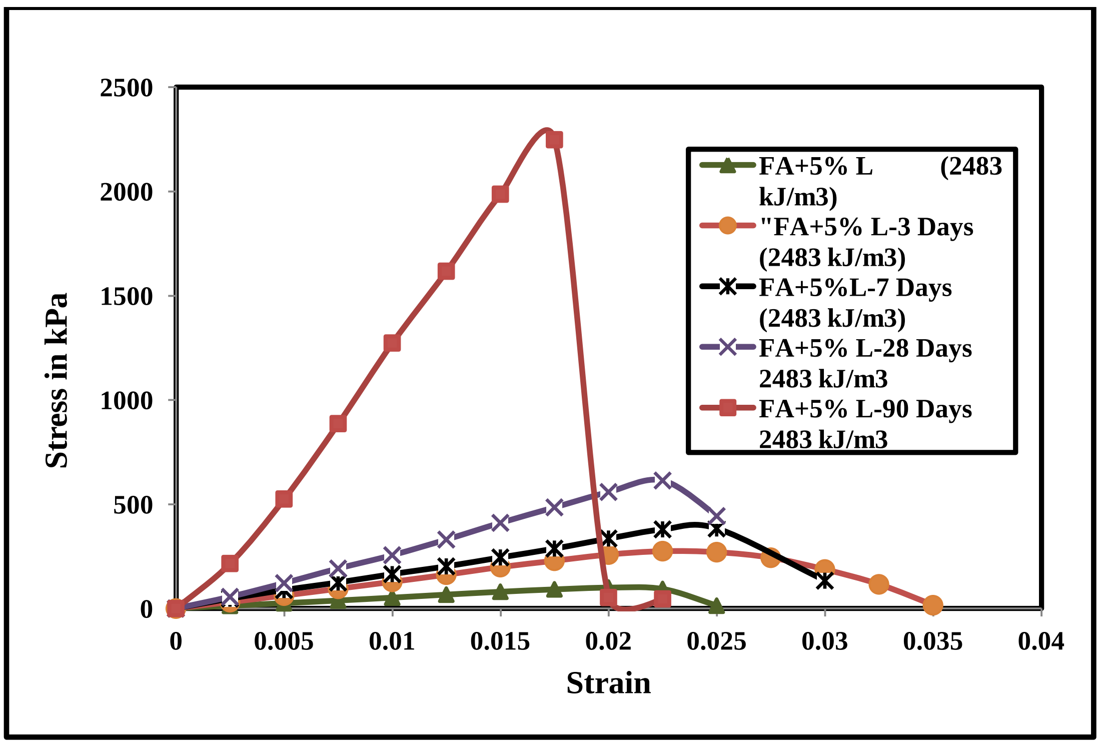

Figure 5.27: Stress-strain curve of FA+5%L at a compactive energy of 2483 kJ/m^3

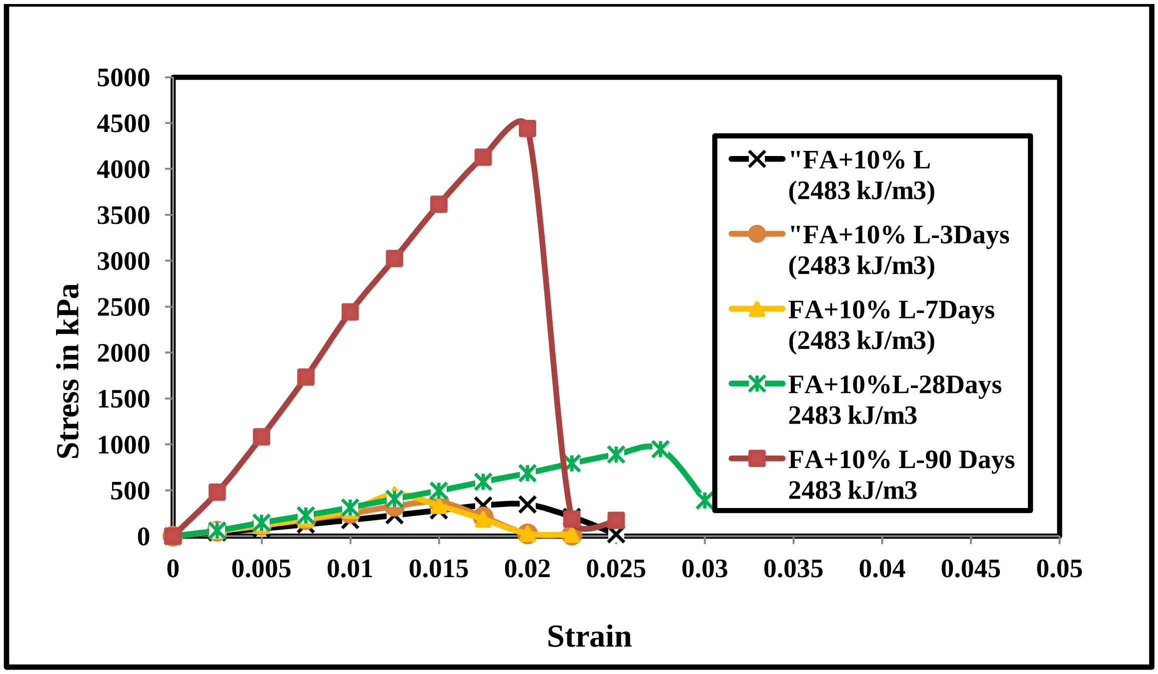

Figure 5.28: Stress-strain curve of FA+10% L at a compactive energy of 2483 kJ/m^3

With increasing compaction energy more sharp peak of stress-strain curve result in more brittle failure Also the failure strain decreases and stiffness increases.

5.3.2.3. Effect of lime content

With increase in lime content the UCS value increases linearly. However the increasing trend is more for sample subjected to 90 days of curing. This is basically due to pozzolanic reaction that became effective after 28 days of curing so relatievely high strength is achieved after 90 days of curing

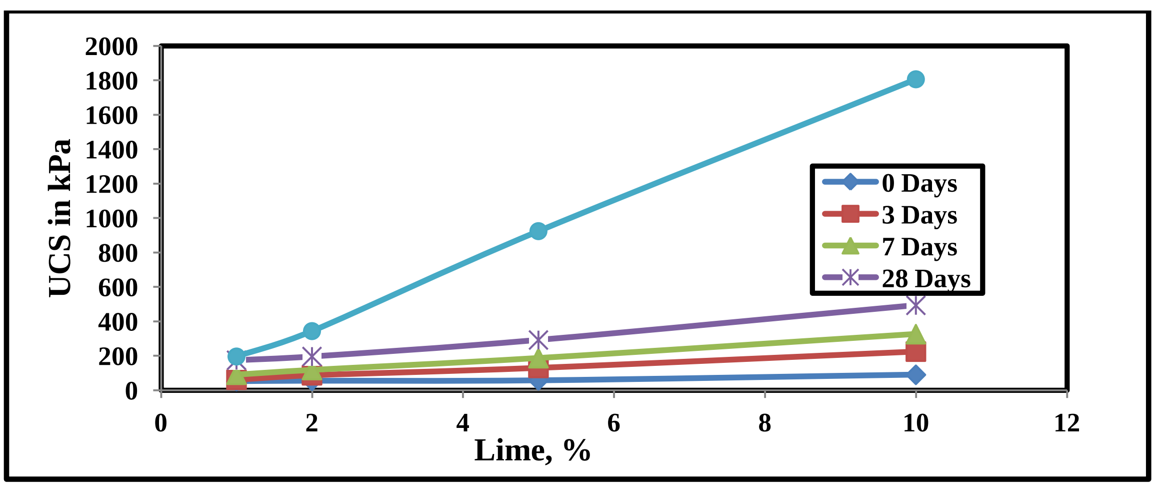

Figure 5.29: Variation of UCS with lime at a compactive energy of 355.8 kJ/m^3

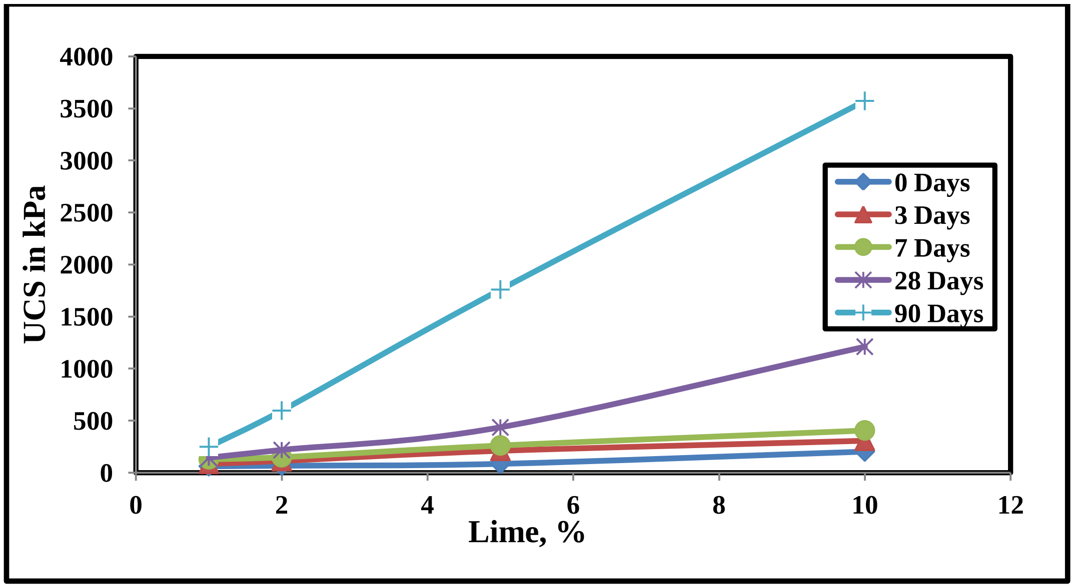

Figure 5.30: Variation of UCS with lime at a compactive energy of 593 kJ/m^3

With 10% lime and 28 days curing the strength has gone up to 947.905 kPa, as against 345.293 kPa for the untreated soil. So there is a linear relation existing between UCS and lime content. The increase of UCS value with percentage of lime became more pronounced after 90 days of curing.

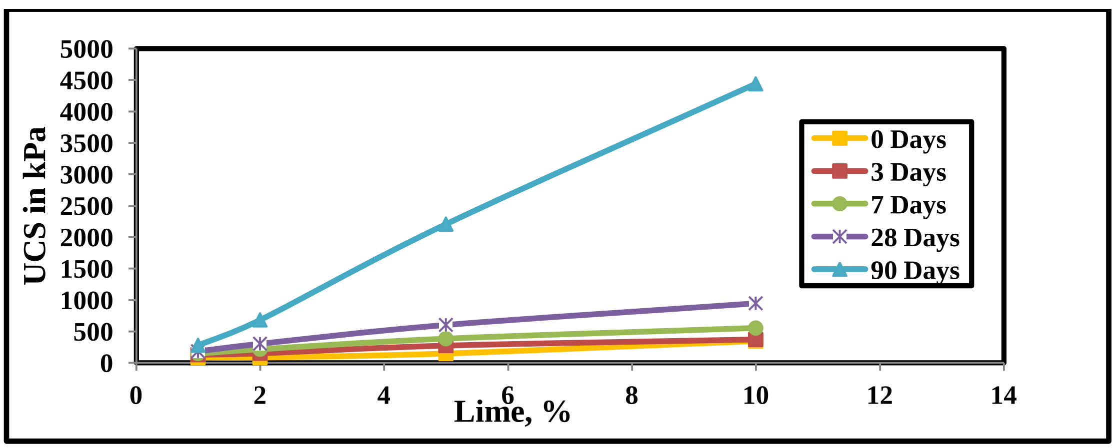

Figure 5.31: Variation of UCS with lime at a compactive energy of 2483 kJ/m^3

5.3.3. CBR Value

Basically the unsoaked CBR value is more than soaked CBR value. CBR values under soaked conditions would always give a highly conservative value for design.CBR value increases with increase in compaction energy.

The soaked CBR value of Fly ash is relatively low ranging from 5.83 kJ/m^3 to 24.69 kJ/m^3 as compaction energy increases from 118.6 kJ/m^3 to 2483 kJ/m^3. However Lime treated fly ash has comparatively higher CBR value reaching a value of 48.52 kJ/m^3 a lime content of 10%.when the sample subjected to a curing period of 24 days and a soaking period of 4 days, CBR value considerably increases due to pozzolanic reaction of lime. The load Vs penetration curve of lime treated fly ash samples are shown below.

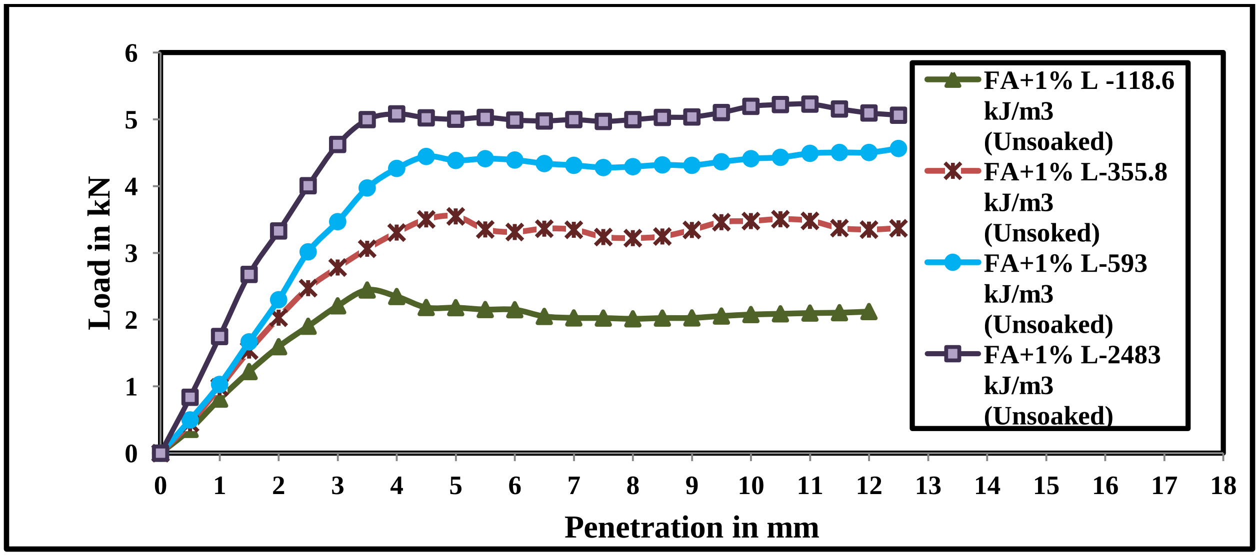

Figure 5.32: Load Vs penetration curve of FA+1% L under unsoaked condition

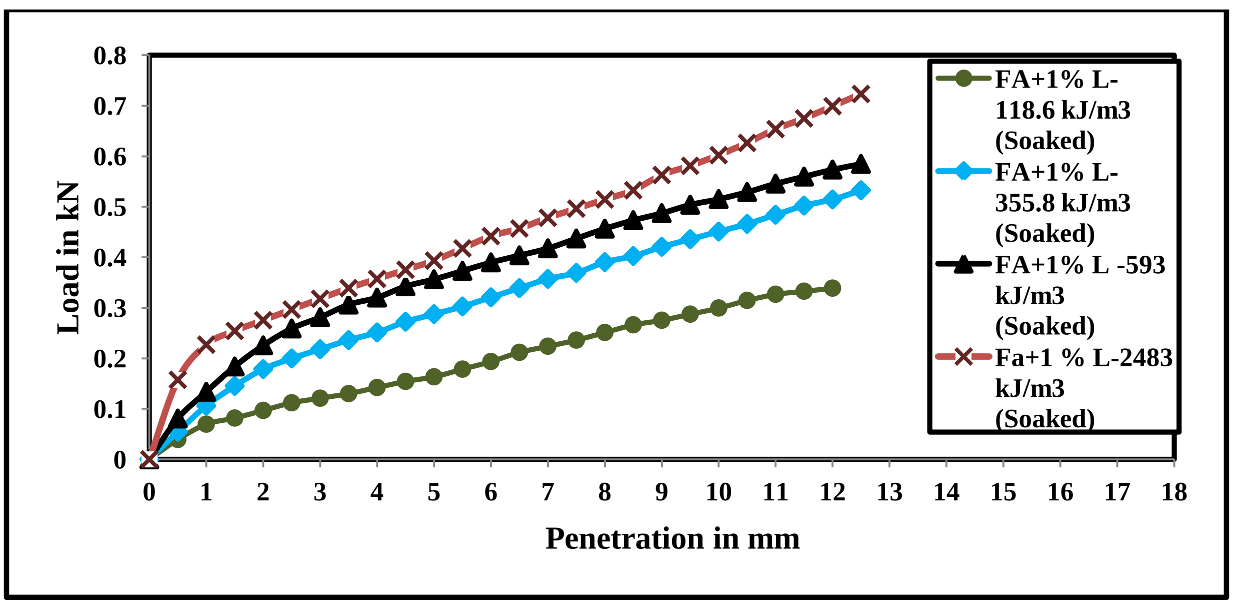

Figure 5.33: Load Vs penetration curve of FA+1% L under soaked condition

With increase in lime content unsoaked CBR value increases .This is due to increase in lime content result in alteration of particle arrangement which in term result in more closer arrangement.

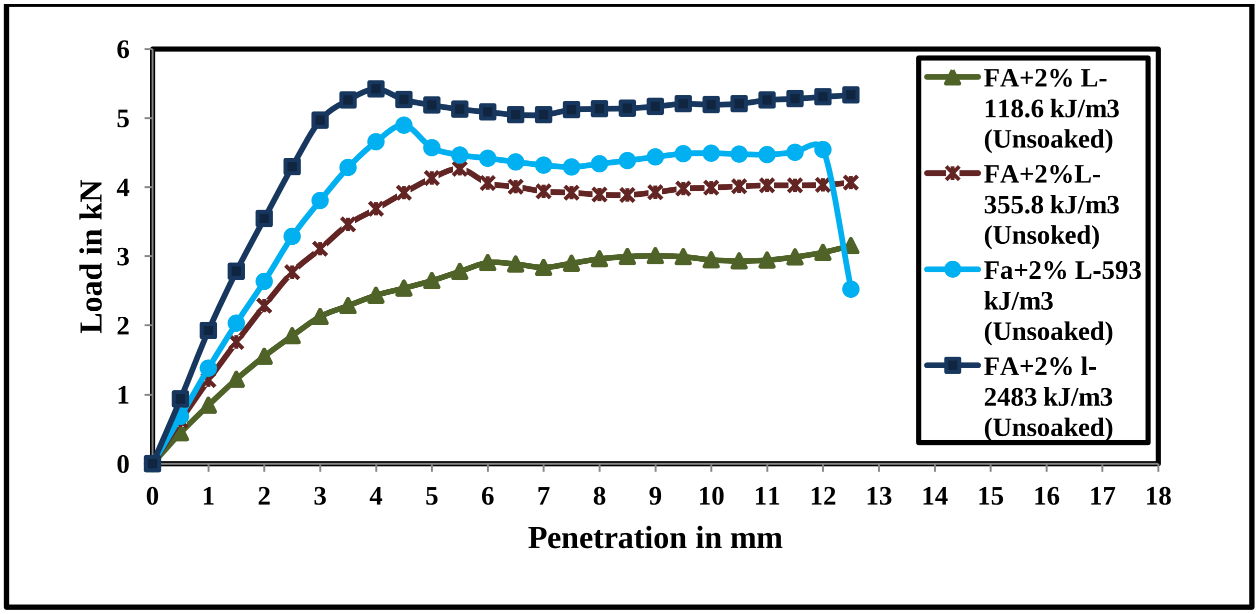

Figure 5.34: Load Vs penetration curve of FA+2% L under unsoaked condition

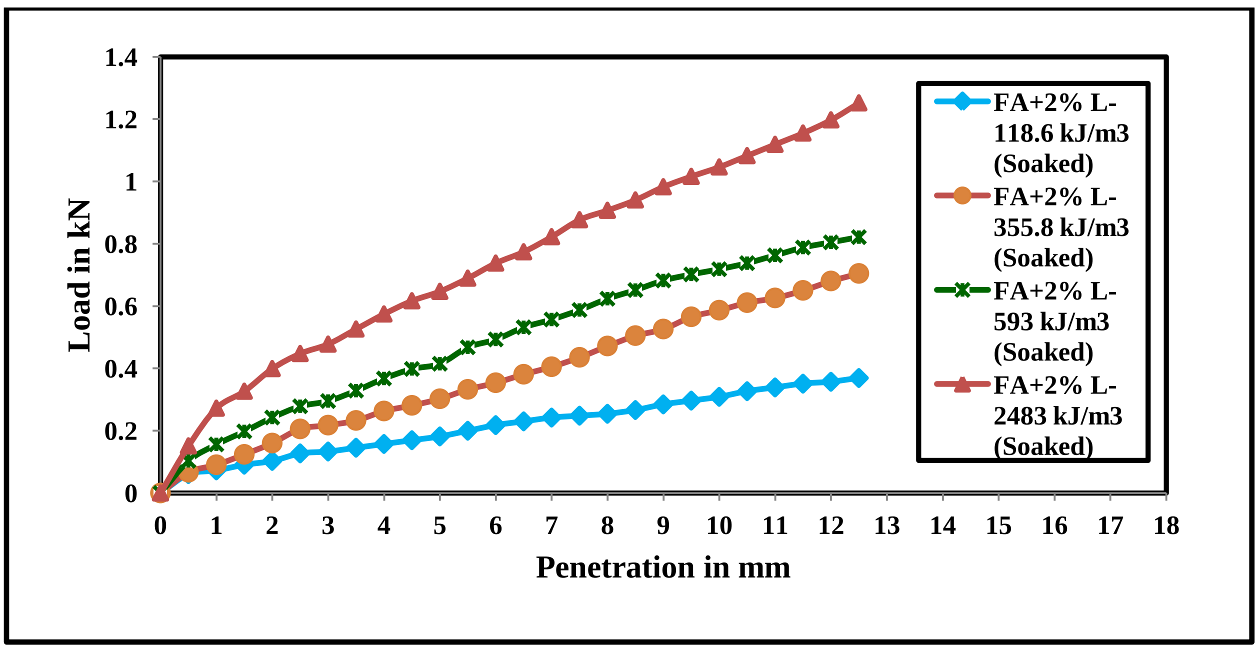

Figure 5.35: Load Vs penetration curve of FA+2% L under soaked condition

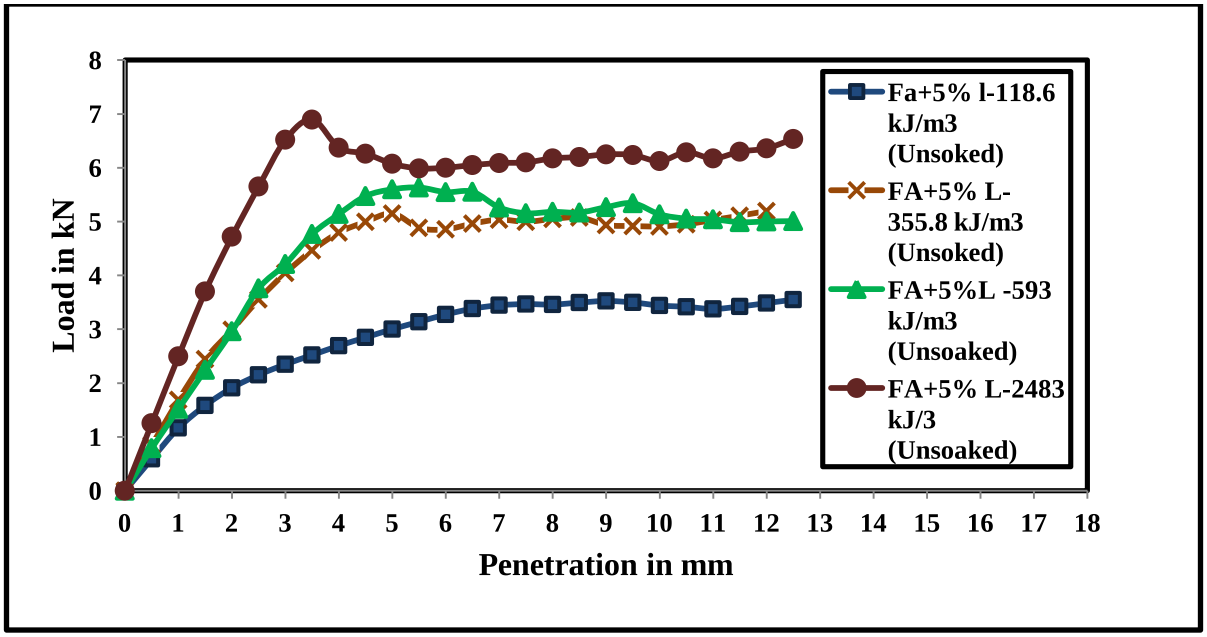

Figure 5.36: Load Vs penetration curve of FA+5% L under unsoaked condition

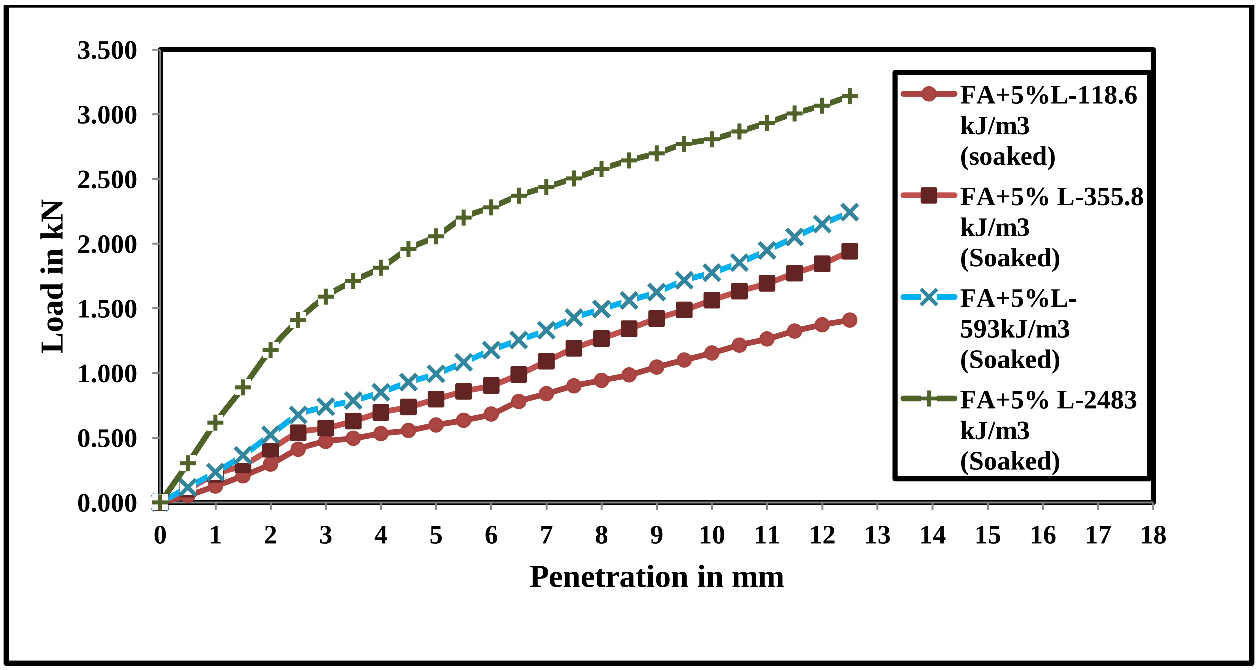

Figure 5.37: Load Vs penetration curve of FA+5% L under soaked condition

However as the samples were subjected to 24 days of curing and 4 days of soaking so lime-fly ash reaction result in cementtious gel that bind the particle together result in increase in soaked CBR value.

Load penetration curve for FA+10% lime under soaked and uncooked condition are shown in figure 5.38 and 5.39 respectively.

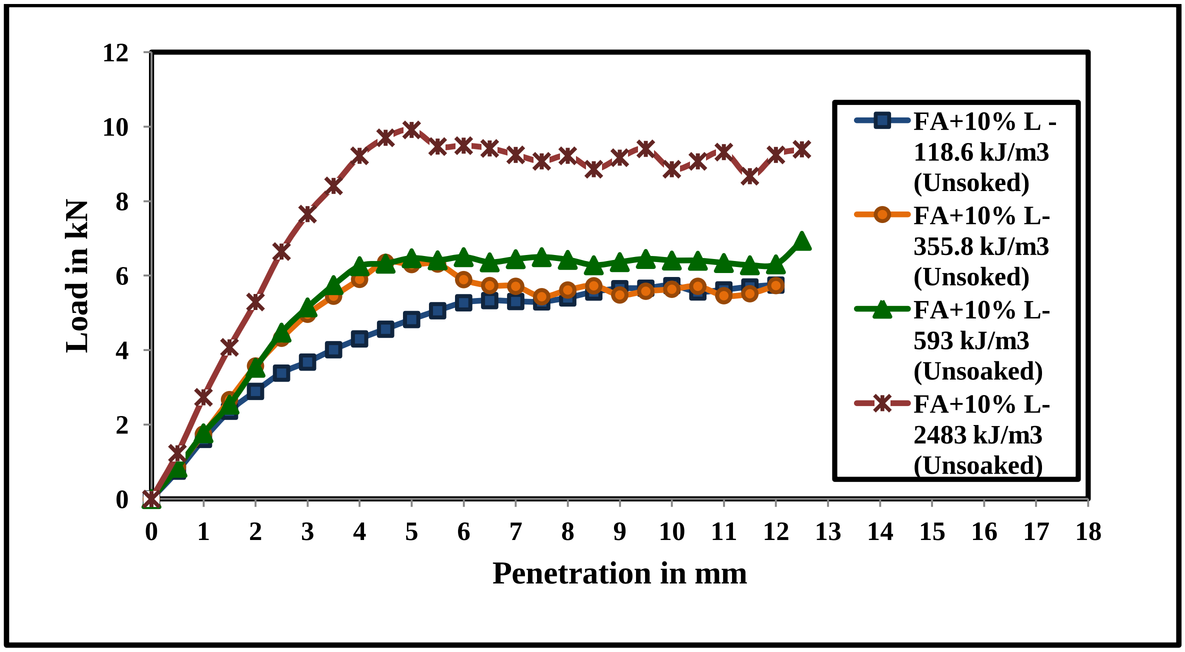

Figure 5.38: Load Vs penetration curve of FA+10% L under unsoaked condition

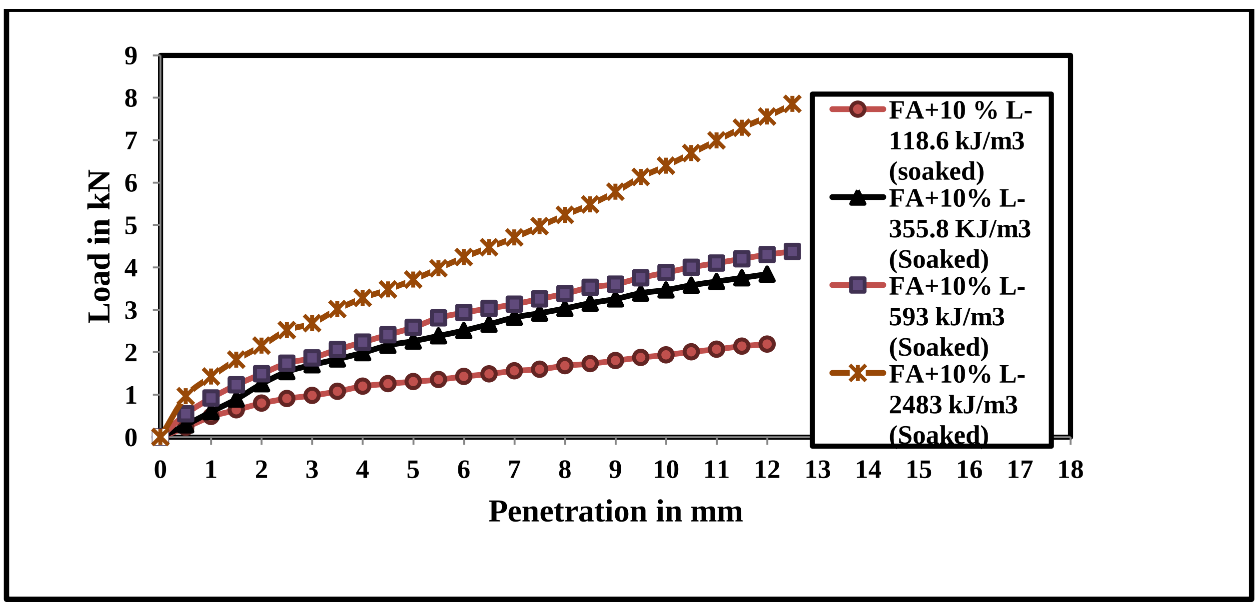

Figure 5.39: Load Vs penetration curve of FA+10% L under soaked condition

Soaked CBR value of fly ash treated with 10% of lime is still less than soaked CBR value as the lime percent is not sufficient to bind all particle. So even after 28 days of curing soaked CBR value do not show significant improvement over unsoaked CBR. As a result, relatively large amount of the lime is needed to bind all the particles leading to visible increase in strength. However according to literature excessive lime result in reduction in strength due to formation of excessive cementiceous gel.

A graph showing the variation of Normalized CBR with compaction energy is shown in figure 5.40

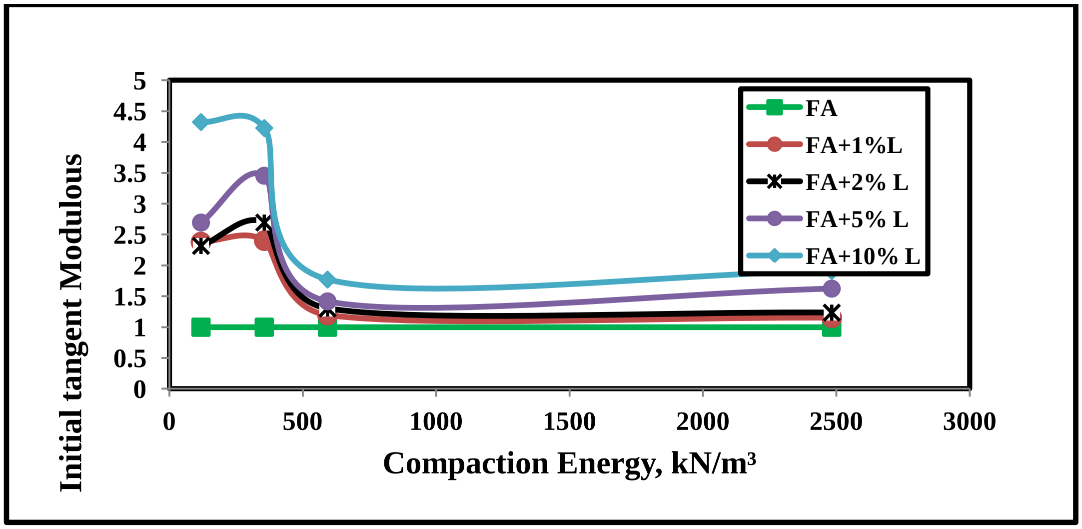

Figure 5.40 Variation of Normalized CBR with compaction energy for unsoaked CBR test

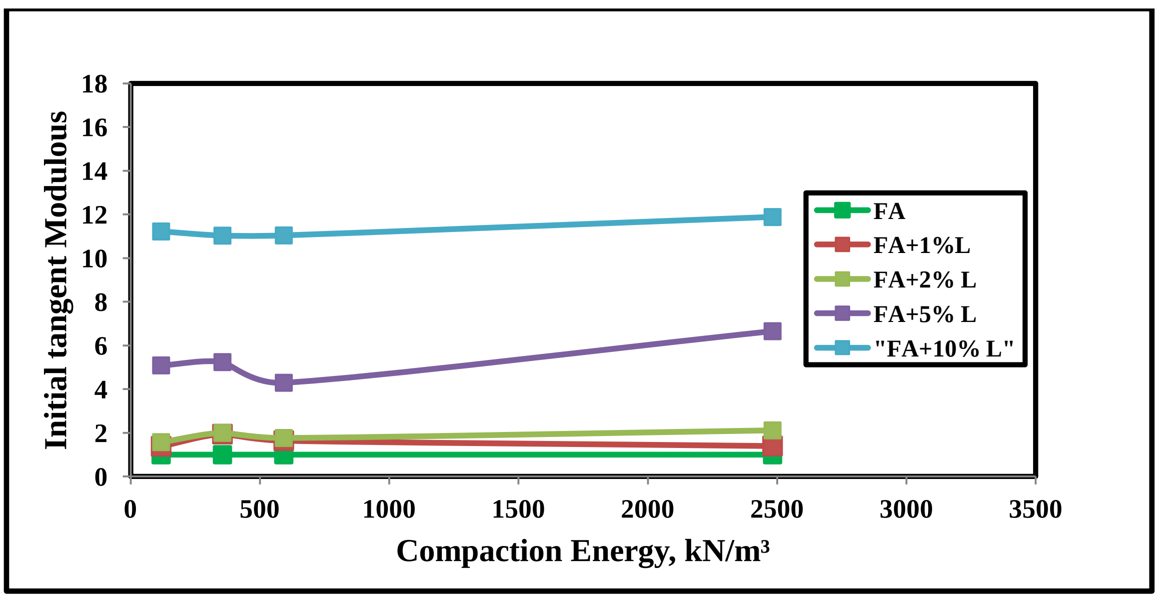

Figure 5.41 Variation of Normalised CBR with Compaction energy for soaked CBR test

Increase in compaction energy increases the Initial tangent modulus of Lime treated fly ash which result in increase in stiffness. The variation of Initial tangent modulus with compaction energy is shown in Figure 5.42.

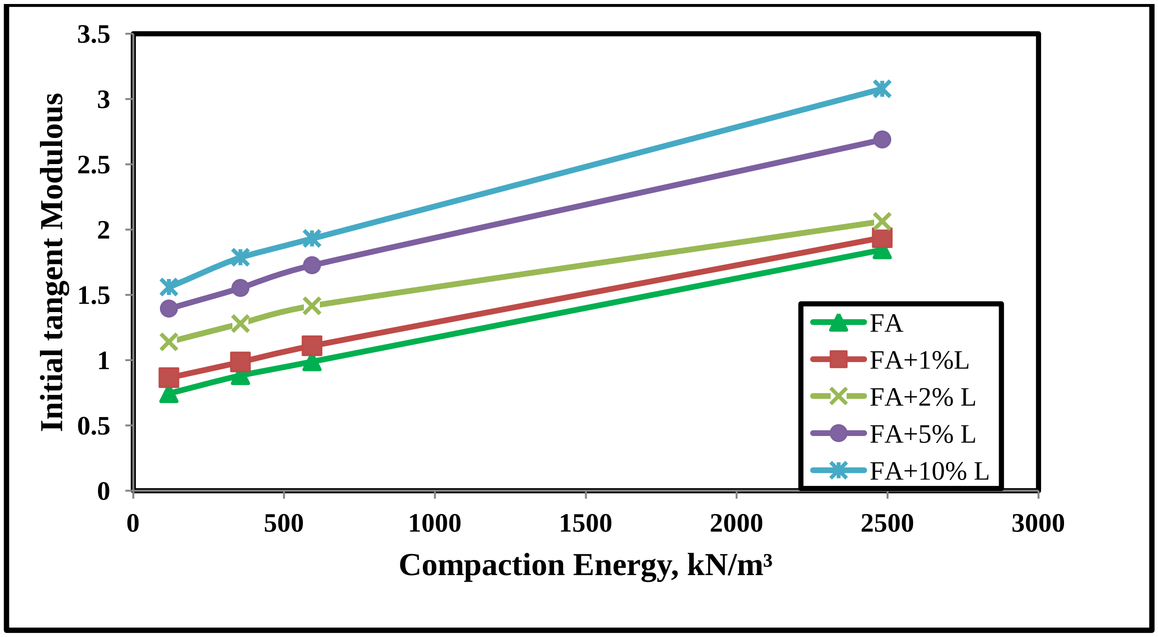

Figure 5.42: Variation of Initial tangent modulus with compaction energy for unsoaked CBR test

This graph shows a linear relationship between Initial tangent modulus Ei and compaction energy which indicates that Ei increases with increase in compaction energy. The graph showing the variation of initial tangent modulus with compaction energy for soaked CBR test is given below. These also follow the same trend as unsoaked CBR test.

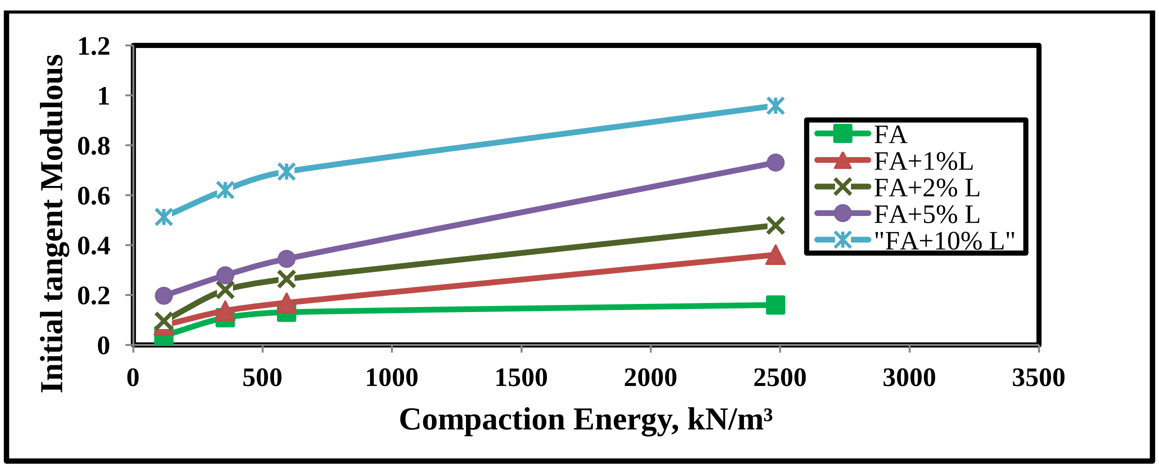

Figure 5.43: Variation of Initial tangent modulus with compaction energy for soaked CBR test

5.3.3.1. Effect of Lime Content

In conclusion, it can be stated that, fly ashes mixed with additives can be effectively used as sub-base materials even under soaked conditions. Addition of lime increases the Soaked CBR value.

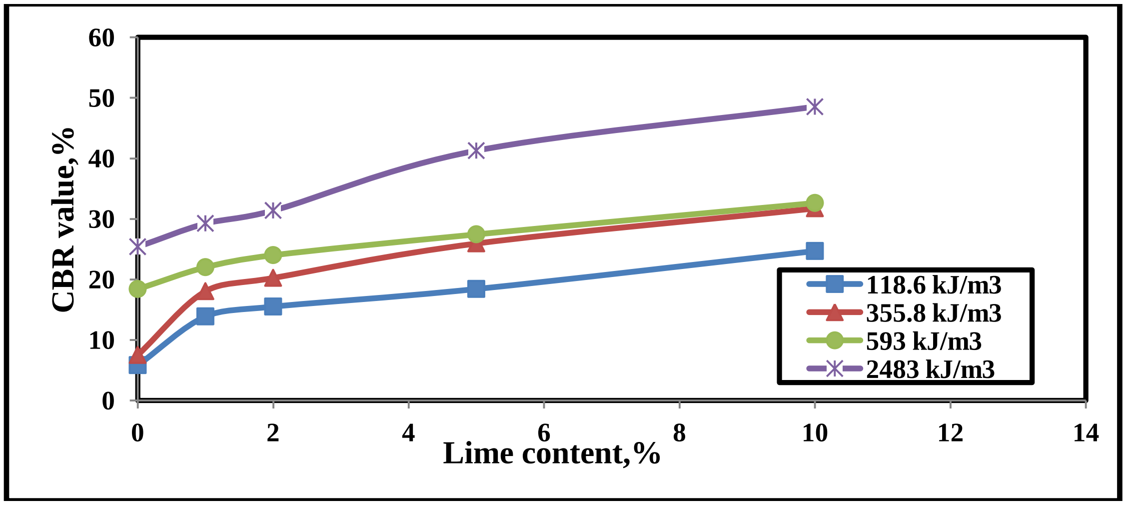

Figure 5.44: Variation of unsoaked CBR with Lime content

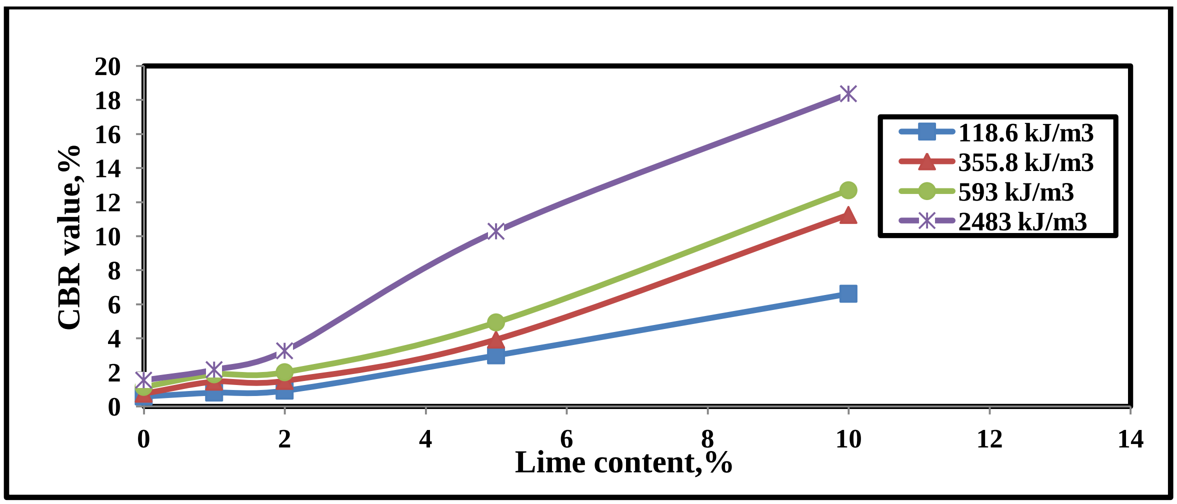

Figure 5.45: Variation of soaked CBR with Lime content

Increase in CBR value is not remarkable up to addition of 2% lime. After that the CBR value increases linearly .However increase in CBR value continue up to a certain percent of lime after that CBR value decreases. 28 days of curing under some surcharge considerably increase the soaked CBR value. Also this soaked CBR value again increases with increase in percentage of lime as more lime available for pozzolanic reaction. Maximum soaked CBR value obtain for fly ash stabilized with 10% of lime was found to be 18.37.

A graph showing the variation of Normalised CBR and Normalized UCS are shown in figure 5.46

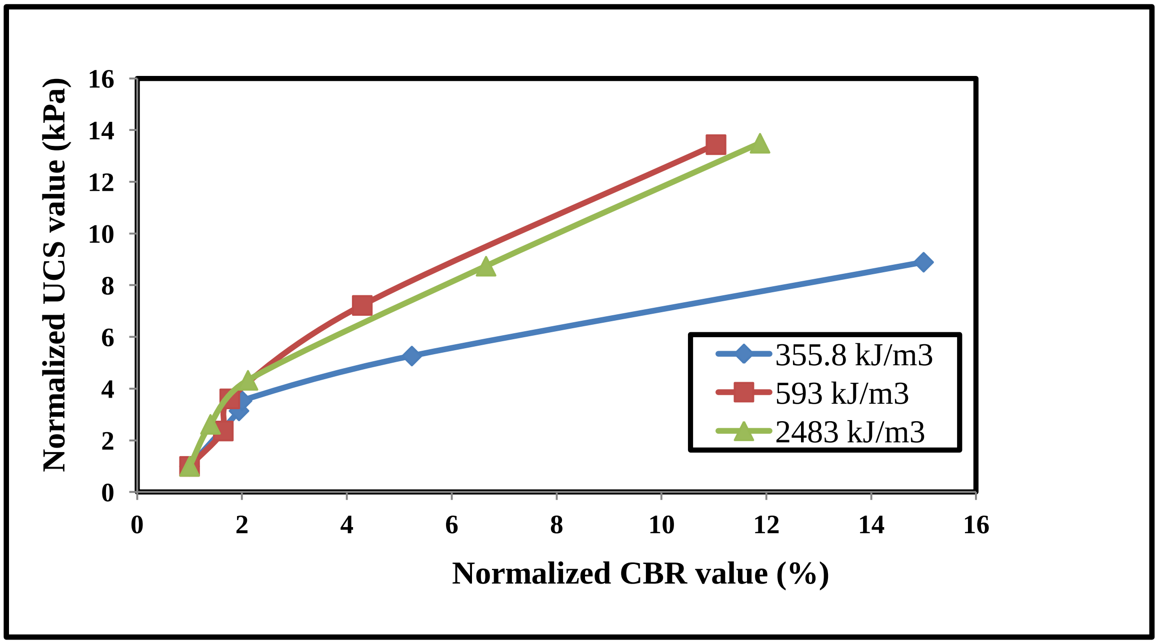

Fig 5.46: Relationship between UCS Vs CBR values

This graph basically shows that with UCS value increases linearly with the CBR value.CBR value mostly related to strength in confined condition and UCS value mostly related to strength in unconfined condition. From this graph it is clear that strength of lime treated fly ash increases with lime both in confined and unconfined condition

5.3.4 Permeability

A graph showing the variation of Co-efficient of permeability with compaction energy is given below. Permeabilty decreases with increase in compactive energy. At compaction energy of 2483 kJ/m3 the co-efficient of permeability vary from 7.65×10^{-5} cm/sec for untreated fly ash to $.371\times10^{-5}$ cm/sec for fly ash treated with 10% lime. 28 days curing of lime treated fly ash sample in a permeability mould before permeability test result in decrease of permeability. Effect of compaction energy triggered with the addition of lime result in more compact arrangement of particles .sillica oxide and alumina oxide of fly ash react with lime to for cementitious gel(CSH) that bind particle together blocking of the flow paths thus reducing the value of coefficient of permeability the lime treated fly ash specimens.

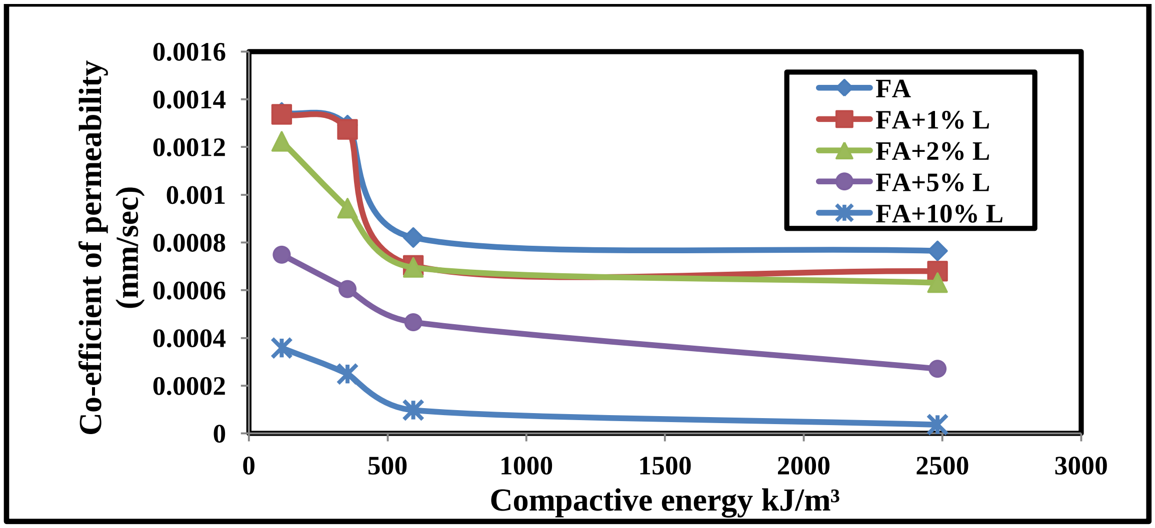

Figure5.47: Variation of co-efficient of permeability with compactive energy.

CHAPTER 6
CONCLUSION

6.2. CONCLUSION

- The fly ash consists of grains mostly of fine sand to silt size with uniform gradation of particles. The percentage of Fly ash passing through 75µ sieve was found to be 86.62%. Coefficient of uniformity (Cu) and coefficient of curvature (Cc) for Fly ash was found to be 5.88 & 1.55 respectively, indicating uniform gradation of samples. The specific gravity of particles is lower than that of the conventional earth materials.
- An increase in compaction energy results in closer packing of particles resulting in an increase in dry density where as the optimum moisture content decreases.
- Dry unit weight of compacted specimens is found to change from 1.142 to 1.255 kJ/m^3 with change in compaction energy from 118.6kJ/m^3 to 2483 kJ/m3, whereas the OMC is found to decrease from 30.2 to 24.2 %. This shows that fly ash sample responds very poorly to the compaction energy. With addition of lime maximum dry density decreases and optimum moisture content increases. Addition of lime results in filling the voids of the compacted fly ash thus increases the density.
- The failure stresses as well as initial stiffness of samples, compacted with greater compaction energies, are higher than the samples compacted with lower compaction energy. However the failure strains are found to be lower for samples compacted with higher energies. The failure strains vary from a value of 0.75 to 1.75%, indicating brittle failures in the specimen.
- A linear relationship is found to exist between the compaction energy and unconfined compressive strength.
- The UCS value is found to change from 32.764 to 47.271 kPa with change in compaction energy from 118.6kJ/m^3 to 2483kJ/m^3 indicating that the gain in strength is not so remarkable. It revealed from the test results that a linear relationship exists between the initial tangent modulus with unconfined compressive strength and deformation modulus.
- Increase in curing period of lime treated fly ash specimen show improvement in the UCS value. However the gain in strength with curing period is more in initial days of curing which tends to decreases with increase in curing period.
- With increase in compaction energy followed by curing period shows a significant increase in strength due to closer packing of particles. Besides, when lime is small in quantity, that's about 1%, the strength improvement is practically negligible, even if cured for long. With increased lime content the pozzolanic reaction peaks up producing adequate amount of cementitious compounds leading to visible increase in

strength. As the lime percentage increases this facilitates the pozzolanic reaction that form cementiceous gel that binds the particles. This process is catalyst by increase in curing period. Increased duration of curing, leading to prolonged pozzolanic reaction and result in increase in strength.

- The unit cohesion and the angle of internal friction vary from 10.7 to 13.4kPa and 24.84 to 27.34 degree with the change in compaction energy from118.6 kJ/m^3 to 2483kJ/m^3. Low value of angle of internal friction is due to lack of proper interlocking among particles as the fly ash mostly contains spherical particles with uniform gradation. There is negligible increase in cohesion component with compaction energy.
- The highest unsoaked and soaked CBR value are found to be 25.39% and 1.546% at compaction energy of 2483 kJ/m3.This indicates that CBR value of compacted ash is very susceptible to degree of saturation.
- The unsoaked CBR value is more than soaked CBR value. Even after 28 days of curing of samples with lime content of 10% the soaked CBR value do not show significant improvement over unsoaked CBR. This indicates that, relatively large amount of the lime is needed to bind all the fly ash particles together, leading to visible increase in strength.
- Permeability decreases with increase in either compactive energy or lime content. Permeability is basically a function of grain size and compactive effort. With increase in lime content, pozzolanic reaction occurs which result in blocking of the flow paths thus reducing the value of coefficient of permeability of the lime treated fly ash specimens.

CHAPTER 7

SCOPE FOR FUTURE WORKS

6.1. FUTURE WORK

For effective utilization of lime treated fly ash, some more aspects have to be investigated.

- Compressibility and Consolidation characteristics of compacted fly ash.
- Bearing capacity of surface and embedded foundations.
- Effect of other natural and synthetic additives on geo-engineering properties.
- Liquefaction susceptibility of fly ash.
- The environment aspects arising out of the leachate from the compacted fly ash.

Chapter 8

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